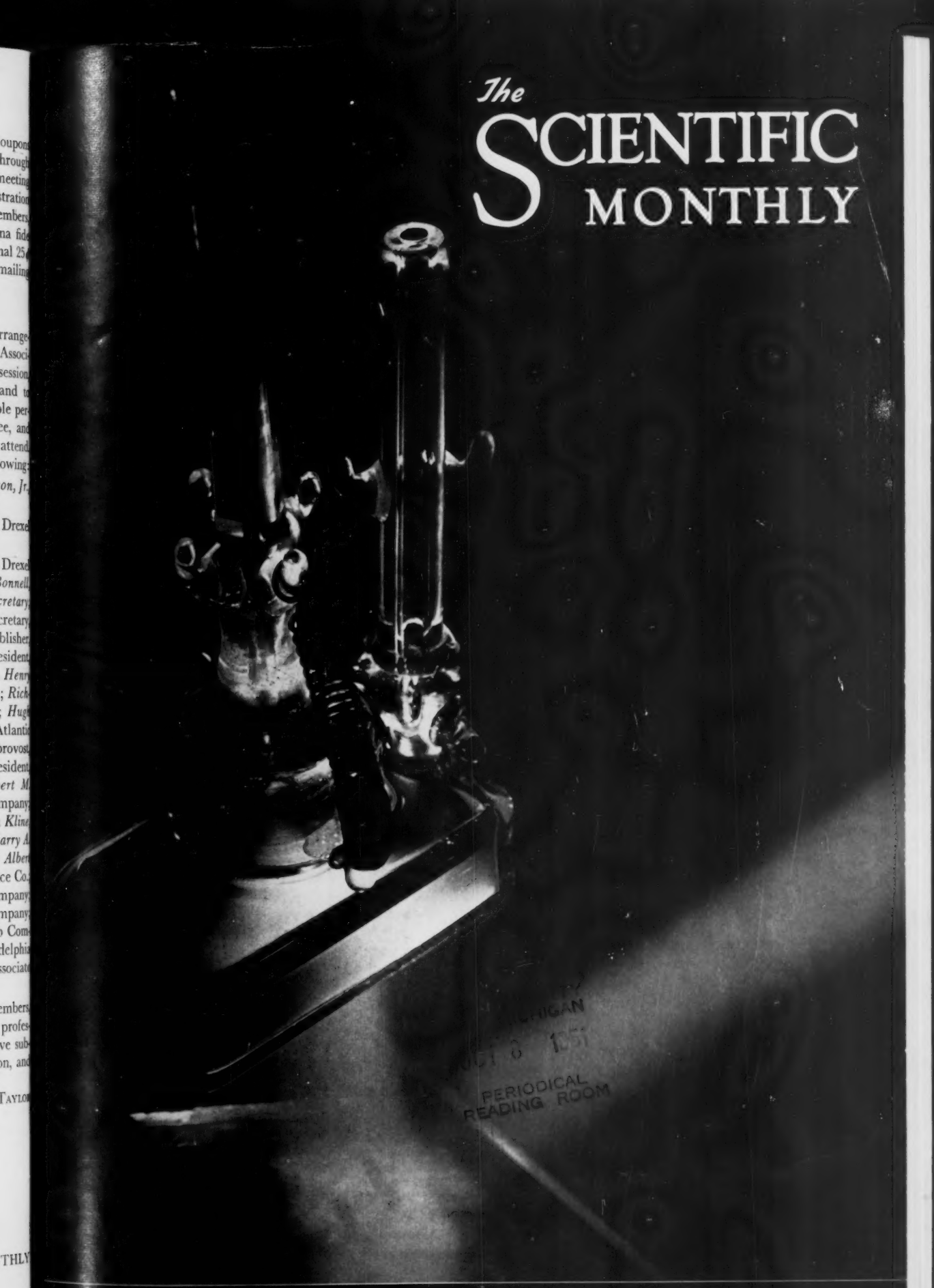
The
SCIENTIFIC
MONTHLY
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What GENERAL ELECTRIC People Are Saying

F. C. KRINGS

Apparatus Department

MICROWAVE FOR UTILITIES: Recently there has been a vast interest shown in microwave as a form of communication for the electric utilities. This interest arises from the availability of microwave frequencies and microwave equipment for use in operating and dispatching channels. It is important, therefore, that this new method should be properly evaluated.

Frequency bands in the range between 950 and 30,000 megacycles are among the space radio-frequency bands assigned by the Federal Communications Commission for utility-company use. These frequencies are among those called microwave and require a line of sight from one antenna to the other with approximately a 50-foot clearance above intervening objects.

One of the attractions of a microwave channel is the band width that is available. This wide band width permits the simultaneous transmission of several voice and control channels. . . .

The objectives of a utility's dispatching and operating communication are these: To achieve reliable telephone service for its dispatching; dependable supervisory control over its unattended substation; accurate and dependable telemetering and load control of the power flow over its tie lines; and the high-speed selective relaying obtainable by using a pilot form of relaying.

The reliability of these services is of great importance, and they should be operable under all weather conditions. Terminal equipment and power supplies for the equipment should be immune to failure, and maintenance requirements should be such as to require only short outage time on a planned basis.

Because microwave and carrier are both capable of supplying the channels for the operating and dispatching communication needs of an electric utility company, the choice is largely determined by economics and reliability. In many cases, the reliability requirement will become the predominant factor. . . .

Microwave tends to be suitable for a large number of channels between terminal points; in other words, multichannel installations. . . . Carrier tends to be more suitable for party-line channels to scattered points. . . . Not only is there a definite place for microwave and a definite place for carrier, but also they can supplement each other.

General Electric Review

July, 1951

☆

J. H. CAMPBELL

H. E. SCHULTZ

Lamp Department

OLD LAMPS VS. TELEVISION: It has been known for some time that vacuum-type filament lamps with a straight-draped wire filament could produce radiation at television frequencies. In fact, tests were conducted in Bridgeport and Schenectady as early as 1940 on various types of filament lamps furnished for the purpose by the General Electric Company's Lamp Department. These tests revealed that only the S-1 type of filament in vacuum caused sustained oscillations that could be picked up by the television antenna or the unshielded parts of the receiver.

Lamps of this type for home lighting were not manufactured after 1925, so the problem is not generally considered a serious one as compared with other sources of interference. However, since there are now over 12,000,000 television sets in operation, it is understandable that many older homes contain one or more of the veteran lamps as well as a television receiver.

The radiation can be reflected away or dissipated by applying various types of metal reflectors, but no one recommendation will apply to all installations. The best and least expensive cure is to replace these veterans of 25 to 40 years with a modern lamp, which produces light at much higher efficiency and costs about one-third as much to buy as the old ones did. On an equal light-output basis, one of the modern 60-watt lamps is equivalent to 3¼ of the old 25-watt lamps.

General Electric Review

July, 1951

You can put your confidence in

GENERAL ELECTRIC

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Annual Meeting, AAAS, Philadelphia, Pennsylvania, December 26–31, 1951

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Science and Technology

(From the Month's News Releases)

Painting Could be Fun

An all-purpose paint roller uses a Lonel dynel cover, which applies rubber-base, or water-thinned paints, enamels, or aluminum paint, does not mat, coagulate, or slip. Removable covers can be purchased separately. Dynel is said to clean easier than lamb's wool and to be like new after cleaning.

Note for Uranium Prospectors

A pocket-size uranium test kit used in conjunction with any type of ultraviolet instrument eliminates the necessity of shipping radioactive samples to a testing laboratory for determination of uranium. All elements are standard and individually replaceable. From 25 to 30 bead tests can be made from a single kit.

Safety Insurance

Gyro-Stabilizer is said to maintain an even weight distribution on curves, sharp turns, down grades, through rough and uneven surfaces, and on wet and icy pavements. All-metal, simple to install, and usable on all makes of cars, it attaches to rear cross member of the car.

The Greeks Had a Name for It

Nephos supplied the inspiration for the naming of the photo-nephelometer, a small laboratory instrument used in hospitals and research laboratories to detect bacterial contamination in serums; in distilleries to measure cloudiness in whiskies; and in high-pressure boilers to detect calcium, magnesium, chlorides, and other impurities in the water.

Maple Mite

Nothing can be done at this time of the year about those small blisters on the leaves of maple trees. Caused by the feeding of tiny mites, the galls or blisters do no harm, although they disfigure the foliage. Next spring, just as the bud scales begin to separate, one application of a spray of lime sulfur and water (1:10) will probably control the pest.

There's Always DDT

The USDA has released horrifying figures on the possible reproduction of rice weevils in stored grain, provided they can live under ideal conditions. The female will lay about 300 eggs, and by the time the fifth brood appears 120 days later, 151,875,000,000 weevils could have made their appearance. Fortunately, few insects encounter conditions favorable to such astronomical multiplication.

High-speed Camera

Eastman Kodak has modified its high-speed camera to permit both the mechanical and electrical aspects of a subject to be recorded simultaneously on the same film. A second lens has been added to the camera to record the images on the tube of a cathode-ray oscillograph through the back of the film while the mechanical aspects are being photographed on the front. The oscillographic modification may be added to the high-speed camera you now own.

Dialing in the Dark

Glo-Dile, an inexpensive luminous telephone dial, is made of two plastic halves that lock in place between the dial rotary and the dial face. Useful for blackouts, power failures, sickrooms, hospitals, mines, etc.

Gardeners' Notes

Vitamulch, said to come from volcanic ash in the Grand Canyon country, will air-condition and water the roots of plants almost automatically, because of its ability to retain water, plus low rate of evaporation. Metal and ceramic planters, the manufacturer boasts, will need to be watered only once in three weeks. On the other hand, if you prefer a self-watering flowerpot there is the plastic one with a fiber wick that carries moisture by capillary action to the plant roots from a black pedestal base. Among other gardening aids are reusable markers of plastic on 14-inch, steel supports that hold the label tilted at an easy-reading angle. Measuring 2¾ × 1½ inches, the markers come in neutral green, orange, or translucent dark green. Special rainproof pencils are used to write on the plastic surface from which the marks may be easily erased.

Double-Purpose Rule

Designed primarily for the USAF, the Aerial Photo Rule has many applications. One side bears an altitude scale, a focal-length scale, two image size scales (in feet and in centimeters), a ground size (feet scale) for settings in either mph or knots. The reverse side bears L, A, DF-CF, CIF, T, S, C-D, DI, and K for general computations. It is boxed in a leather case with manual in two sizes, 10-inch government model and 6-inch pocket government model.

Resists Thermal Shock

A heat-absorbing plate glass produced by Libbey-Owens-Ford is pale bluish-green and in ¼-inch thickness has a transmittance of 76.5–79 percent of average daylight, but passes only 42–50 percent of the total radiation of the sun. These factors make it desirable in show windows for the display of fruits, flowers, candy, vegetables, and baked goods. It is also useful in air-conditioned buildings.

Address a post card to Science & Technology, 1515 Massachusetts Ave., N.W., Washington 5, D. C., for further information about any item on page iv.

THE
SCIENTIFIC MONTHLY
OCTOBER 1951

Medical Aspects of Military Manpower Selection*

WALLACE O. FENN

The author was trained at Harvard and has been professor of physiology in the University of Rochester School of Medicine and Dentistry since 1925 and assistant dean since 1950. He has worked on the physiology of nerves, muscles, and electrolytes and in recent years has been investigating problems of respiratory physiology of particular interest to the Air Force. He is a past president of the American Physiological Society, and a member of the RDB Committee on Medical Sciences.

THE Research and Development Board—specifically its Committees on Medical Sciences and Human Resources—is concerned with the methods by which men and women made available for military purposes are screened, selected, assigned, and cared for. In general, the Committee on Human Resources supervises research and development on new and improved methods of assessment, selection, assignment, and evaluation of personnel, and the Committee on Medical Sciences is responsible for research relative to the adaptation of the personnel to the various vehicles of warfare and environmental stresses and for their mental hygiene and psychiatric rehabilitation. In other words, the Committee on Human Resources is charged with seeing that the selection tests are adequate, and the Committee on Medical Sciences must ensure that the men and women selected adapt properly to their military environment and do not break down under stress. The two committees have, therefore, a common interest, which is about equally divided; in the last analysis, the same problem concerns both. How shall men be selected so that failures may be avoided? Our work on an answer to this question begins after determinations have been made by other defense and nondefense agencies regarding the size of the required military force, the manpower needs of industry, and the policies to be followed regarding deferment.

The earliest recorded evidence of a military manpower selection problem that I can recall appears in the Old Testament, Chapters 6–8 of the Book of Judges. There it is recorded that Gideon was called upon by God to raise an army to smite the Midianites. Gideon responded by raising an army of 32,000 men, but the Lord told him that it was too large and that its success would be impaired by the cowards within the ranks. So Gideon told all those who were afraid to fight the Midianites to go home. He was left with 10,000 men. This may be regarded as the first use of the personal interview or personal preference as a screening procedure. The Lord then told Gideon that his army was still too large and devised a performance test to screen out those recruits who were most alert to their soldierly duties. To this end, Gideon led his men to the river for a drink, where he eliminated all those who carelessly threw down their shields and spears and lapped up the water

* Based on a presentation made by the author at the Symposium on the Selection of Military Manpower, sponsored by the National Academy of Sciences, and held in Washington April 12–14, 1951.

like dogs, with their backs to a possible enemy. He retained only the 300 men who kept a wary eye on the bushes and with spear held ready in one hand scooped up a hasty gulp of water with the other. This ingenious psychological performance test was proclaimed a success, because the Midianite camp was duly liquidated in the night when Gideon's 300 men smashed their pitchers, revealed their circle of lights, blew their war trumpets, and rushed upon the unsuspecting sleepers.

I cannot vouch for the accuracy of the story as I have related it, but I can point out that the experiment *lacked a control*; and there is no proof that the well-hydrated men who drank on their knees would not have killed even more of the enemy than the more cautious selectees. Perhaps that is why Gideon's divinely inspired test is no longer used.

Modern Screening Tests

What can we say of the success of the selection techniques now in use in the armed services after years of research? I suspect that most of them also lack controls even in this scientific age, and that the assignment of a recruit according to his first preference is still the most important single guide in our selection technique.

Doctors of medicine may be said to apply the first screening when they eliminate those recruits who are regarded as unfit, physically or mentally, for the rigors of military service. This is largely a medical problem, and the present physical standards are open to amendment in the light of our practical experience with the standards used in the last war. I do not believe that any attempt is made or should be made in this preliminary screening to include only those individuals who are considered fit for anything that a man can be expected to do, from picking up cigarette butts to operating a jet plane. Some may be accepted for general service and some for limited service. I assume that all are included who are considered worth their keep in the military service.

After this preliminary screening, the psychologist and psychiatrist will apply certain tests to determine aptitudes for special skills, and the physiologist will perhaps be called upon to apply other tests based on the physiological functions of the organism to determine the adaptability to different environments. Indeed, at its last meeting the Panel on Military and Field Medicine of the Committee on Medical Sciences recommended that efforts be intensified to select men who were medically adapted to their particular tasks; in other words, that a positive medical selection be made, rather than a purely negative elimination of the physically unfit. We are particularly concerned with this area today, because the value and predictability of these psychological and physiological tests are less evident and more in need of validation than are the strictly medical tests.

When selecting the men with the best hearing for underwater sonar work or men with the best night vision for night flying or sentry duty, the problem is fairly straightforward and the results of testing are successful. It is more difficult to select men who are best fitted for satisfactory over-all performance in unfavorable physical environments that are too high or too low, too hot or too cold, too wet or too dry. The fatigue that develops under such conditions is too dependent upon motivation and other psychological factors that are hard to measure. It is only in tasks involving strenuous muscular activity that the body is sure to tire before the mind. Consequently, it appears to me that the physiologists have, on the whole, less chance of success with their tests than have the psychologists. When expressed in common terms of performance, the variations in the psychological characteristics available to measurement seem to cover a wider range than the variations in physiological characteristics that remain in this medically selected group. I defer to the experts in this matter, but I should be inclined to guess that the success of an airplane pilot would depend 90 per cent on his psychological characteristics and only 10 per cent on his physiological equipment. The success of an arctic or desert soldier might depend 75 per cent on his motivation and determination and 25 per cent on his heart and lungs. Under sufficiently extreme conditions, it would depend 100 per cent, of course, on his source of artificial heat or his water or oxygen supply. At any rate, both physiological and psychological tests must be applied concurrently for maximum success, and the criteria used require validation in both areas. However great the spirit, the flesh may yet fail, and the greatest of physiques is helpless in the absence of strong and skillful control.

I shall not describe in detail the contributions of environmental physiology to the problem of selection. I do not believe, however, that the problems of survival in the Arctic can be solved merely by selecting men with physiques that adapt well to cold. To a large extent, the solution of the problem will depend upon our success in providing each soldier with a personal nonarctic environment in the form of suitable protective clothing and heating devices so that the stress remains endurable for the average medically selected military man. The same is true for other stresses such as extreme heat and extreme altitude.

The stress of combat is not so easily avoided or minimized. Indeed, modern warfare calls more and more for supermen and is less and less satisfied with those somewhat stupid animal group qualities that appear to suffice for the last desperate banzai charge. The American soldier is given control over weapons with more and more power, which he must learn to use with resourcefulness and cunning—one against many. In spite of our selection techniques, too many men break under stresses of this type. Neuropsychiatric disorder was the largest single reason for discharges in the last war. The Committee on Medical Sciences was informed that, in the years 1942–45, 30 per cent or more of the discharges were for psychoneuroses and personality disorders. The figure is, I believe, about the same in the present Korean war. All these must be regarded as men who slipped through the screening devices. Moreover, we have no idea how many men were screened out who would have been able to withstand these stresses without breakdown. As with Gideon's army, we again have no control. In all reports of the Committee on Medical Sciences this deficiency has been stressed, and the progress being made in investigating the problem and improving the screening tests has been declared inadequate. This was attributed partially to lack of funds, but even more to lack of adequately trained research personnel. This lack is still evident today in spite of valiant efforts to improve the situation by Public Health Service training fellowships and other devices. My own impression is that we have a lot to learn about identifying with certainty the characteristics required for success in combat and that we may never obtain a really satisfactory test that can detect with reasonable certainty their presence or absence in a given recruit.

The Panel on Shipboard and Submarine Medicine of the Committee on Medical Sciences has stated that it is reasonably well satisfied with the present selection technique for submarine personnel, although I am not sure how reliable the validation really is.

In the selection of men as pilots or bombardiers, I believe that the situation is also somewhat better. We no longer make the World War I mistake of eliminating candidates because their postrotational nystagmus was too brief in duration or because they could not maintain a pulmonary pressure of 40 mm Hg for a sufficient length of time.

The impressive nineteen-volume report of the Aviation Psychology Program† indicates the scope of the recent work on this subject. From Report No. 1 edited by John C. Flanagan, I learn that one of the greatest advances was the discovery that academic accomplishments and mathematical and verbal ability have little predictive value for flying proficiency. In this report one can also read of some controlled experiments and some validation of the tests that were applied.

Thus, of 10,000 men selected by a screening test for pilot training, 3.7 per cent of the top 10 per cent and 69 per cent of the bottom 10 per cent failed to graduate. In another, still better experiment, 1,000 applicants were accepted for pilot training, regardless of the scores made on the Air Force screening test. Of the 598 men who passed that screening test, 35 per cent graduated from flight training, whereas only 11 per cent of the 402 who failed to pass the screening test graduated. The tests used for this selection obviously offered some measure of success; nevertheless, they would have eliminated 44 successful flyers out of the 1,000 and they passed 389 men who failed to graduate. In addition, this analysis has neglected the crucial question of whether the ability to graduate from the training school is in itself a fair test of success in combat flying. Perhaps some of those who failed to graduate could have learned to operate planes successfully with a few weeks more of experience, and they might have proved eminently successful in actual combat. May not slow learners sometimes go further in the end, and is not performance in combat a test very different from performance in flight school?

These considerations lead me to wonder whether it is true, on the basis of the record, that research on selection techniques has outrun the administrative use of such tests. I suspect that much still remains to be done in validation of the tests, although I do not mean to underestimate the excellent work already done on this problem by psychologists.

Better Validation Needed

Some years ago, as a member of the National Research Council's Committee on Medical Problems of Civil Aeronautics, I encountered the problem of setting up physical standards of hearing and vision for civil pilot licensees. In this connection, I had an opportunity to attend the meetings of the National Research Council Committee on the Selection and Training of Airplane Pilots which was under the able chairmanship of Morris S. Viteles. At these meetings, a very important experiment was set up in which men with eminently poor vision (the lowest 4.5 per cent of the population) were given the same opportunities to learn to fly as men with perfect vision. About half of this handicapped

† *Aviation Psychology Program in the Army Air Force*, Vol. 1. Washington, D. C.: GPO (1948).

group successfully qualified in spite of poor vision. This is the type of validating experiment that is badly needed in many other areas.

The problem of fatigue in the performance of military tasks is another facet of the problem of selection with which the Committee on Medical Sciences has been concerned. Tests are needed for the selection of those men who do not tire easily at a given task. I have been particularly interested, myself, in the problem of flyer's fatigue. I have made no experimental contribution to the subject, but I have followed the literature carefully and know the inadequacy of any tests that have been devised for the measurement of fatigue. By an effort of the will a well-motivated man can overcome physical fatigue and complete his task with a normal score. Every part of the body is subjected to the stress under investigation, and any part may be the first to show signs of strain. Therefore, no single specific test such as, for example, ketosteroid excretion can cover all eventualities. Only general performance tests remain as possibilities for general applicability. Usually, again, it is the mind that tires before the body. The exact reasons for this are the hardest to determine, and I should think well-nigh impossible to measure.

In connection with this discussion of flyer's fatigue, I cannot refrain from drawing attention to the USSR's ingenious solution of this problem, as described by Subbotnik,‡ who asserts that this phenomenon does not occur among Russian aviators, but as reported elsewhere it is merely the result of the "insufficient material security under which fliers in capitalistic countries live." In other words, the problem is eliminated by simply declaring that it does not exist. However unscientific such an arrogant ukase may be, it has some psychological merit in a people already browbeaten to passive credulity; and it is worth while to inquire whether we have a better practical answer.

I do not pretend to speak with authority concerning this problem of selection of military manpower. The problem is quite analogous, however, to that of selecting medical students for training. As a member of the Admissions Committee of the medical school at the University of Rochester for the past ten or more years, I venture to discuss the subject with some confidence. The use of the medical-aptitude test for purposes of selection has been much debated, and this test is required of all candidates at Rochester, as it is in most schools. We know that it is often quite misleading in individual cases, although it has some validity on a statistical basis. Together with the college record, it aids us in selecting men who can pass set medical examinations and qualify for the M.D. degree. A limited degree of validation is achieved by correlating aptitude-test scores and medical-school grades. The objective, however, is to train successful doctors; and here we have no validation whatever of the efforts of our Admissions Committee. We do not know how to measure success in medicine. It cannot be measured by medical-school ratings, pecuniary intake, number of patients, or number of published papers—nor, perhaps, by anything so ephemeral as community esteem. Have we, in the last analysis, better validation of any of our military selection tests?

‡ *Fundamentals of Aviation Medicine*. W. E. Voyachek, Ed. Trans. by I. Steiman for the National Research Council of Canada, 300 (1943).

And for the Future?

In summary, we must screen in rather than out if we are to stretch the manpower pool to the limit. The first screening, therefore, will not be very discriminating. Thereafter, we need much better tests for the psychological, physiological, and medical selection of men for the many different tasks. Our present tests eliminate many men who might prove quite successful in practice, and pass many men who fail in their tasks or break under the stresses to which they are exposed. Few of the tests have been properly validated, and in many cases there may be reasonable doubt whether we can do any better than Gideon did with his cheap and easy water-drinking test.

The Committee on Medical Sciences is particularly interested in the adaptation of personnel to the military environment, whether it be in a submarine, a jet plane, or the stratosphere. Heretofore, by artificially cushioning the impact of the environment we have made more progress than by the careful selection of particularly well-adapted men. Perhaps it is fair to say that, in selecting men, we still have most success with the method Gideon also used, of giving every man his first preference where possible.

A special case of adaptation to a military environment is the prevention of psychiatric casualties. Here I think the situation is even more serious and the tests are even less satisfactory. The percentage of failures is high, and failure involves some danger of permanent damage to the candidate as well as a waste of time and money in the training procedure. I hope that some new approaches to these problems will be found and that additional impetus may be provided in the search for better selection techniques and for better validation of those now in use. The continued use of a poor selection test is probably worse than no test at all.

The Efficient Transformation of Light into Chemical Energy in Photosynthesis

An Application of the Einstein Law of Photochemical Equivalence to Living Organisms

DEAN BURK, JEROME CORNFIELD, and MARTIN SCHWARTZ

Dean Burk has been head of the Cytochemistry Unit of the Biochemistry Section of the National Cancer Institute, USPHS, since 1949. Interested in the biochemistry of photosynthesis throughout his scientific career, he did his original work in the field for his Ph.D. thesis in 1927. He joined Otto Warburg at the Kaiser Wilhelm Institute in 1948 in a continuation of research they had begun at the National Cancer Institute. Mr. Cornfield is well known as a mathematical statistician. In 1947 he was a member of the Bureau of the Budget Mission to SCAP on reorganization of Japanese statistics. He has been with USPHS since his return. Martin Schwartz' interest in photosynthesis began when he worked with Dr. Burk and Dr. Warburg at Woods Hole in 1949, and he chose this subject for his Ph.D. thesis. He will shortly receive his degree from the University of Wisconsin, after which he plans to go to Germany for work with Dr. Warburg.

Are not gross Bodies and Light convertible into one another, and may not Bodies receive much of their activity from the Particles of Light which enter into their Composition?—Sir Isaac Newton, *Opticks*, Query 30 (1718).

THE economic well-being of any community of organisms, whether of bacteria or of men, is determined in part by the amount of available food. It is thus clear that in large areas of the world today the pressure of population on existing food resources sets an upper limit to the well-being of the population. This, of course, is not a new problem. One hundred and fifty years ago Thomas Malthus, in comparing the growth of human populations in the absence of natural checks (war, famine, pestilence) with that of food supply, decided that the human race tends to increase faster than the food supply and that in consequence a continued pressure of population on resources is to be expected. He concluded that the human race faced the prospect of having this continuing population pressure relieved by the operation of the aforementioned checks—a gloomy prophecy that has not been borne out in the industrialized nations of the world at least.

In recent years the unrelieved poverty of whole continents has resulted in a re-examination of the Malthusian problem. Some students have concluded that in all essential aspects Malthus was correct and that the industrialized nations form only a local exception. Even in these nations, it has been argued, the problem has been met only by unparalleled advances in agricultural technology—better tillage practices, artificial fertilizers, and improved plant varieties. Even if these practices could be extended to all arable land in the world, these students contend, the international standard of nutrition could not be raised to an adequate level, nor could it provide for the inevitable future growth of populations.

We are concerned here with a closely related

problem—the maximum efficiency of photosynthesis. In the green leaf, one of the world's most active chemical laboratories, sunlight provides the energy required to combine carbon dioxide taken from the air and water drawn from the soil. These are put together to form starch and sugar; at the same time oxygen is taken out of water and set free into the atmosphere. Thus, the sun-stoked laboratory creates the food without which man and other animals would starve, and liberates the oxygen without which they would suffocate. This, stated in its simplest terms, is photosynthesis.

Certain experimental work of the past year has greatly extended our understanding of the photochemical phase of photosynthesis and has provided a fundamental, simplified reinterpretation of a great body of data accumulated over past decades. The new findings demonstrate that energy in the form of visible light can liberate oxygen gas in the photosynthetic process with nearly perfect efficiency—that is, with full utilization of radiant energy and relatively little loss of energy in the form of heat. If we can learn how to realize even a fraction of this maximum efficiency under practical as well as laboratory conditions, then the necessity of facing the original Malthusian problem will once again be postponed for many generations.

At present, far less than 1 per cent of the solar energy is ordinarily utilized under even the most effective of modern agricultural practices. The revolution in agricultural technology has therefore taken place within a framework of highly inefficient utilization of the prime mover, solar energy. Consequently, scientific understanding and mastery of this largely untapped part of our natural resources might result in enormous benefit, in a revolution in food production beside which the technological progress of previous centuries might seem trivial.

The Basic Energy Transformation Cycle in Photosynthesis

In the laboratory one can readily demonstrate that food substances such as sugar, starch, fat, or protein can be burned with oxygen to carbon dioxide and water to yield a large amount of energy in the form of heat that can be measured in a calorimeter. All aerobic organisms likewise possess the ability to oxidize food substances to carbon dioxide and water, but nature has enabled them to trap a large part of the available potential energy in the form of bundles of chemical energy before it is converted into heat, in which form it would be wasted. The chemical energy bundles so obtained are used for life functions such as growth, muscular contraction, or passage of nerve impulses. The calorimetric combustion of carbohydrate may be contrasted with the biological oxidation of carbohydrate as follows:

SCHEMA A

Calorimetric combustion:

$$\text{Carbohydrate} + O_2 \rightarrow CO_2 + H_2O + 110{,}000 \text{ cal heat/mole}$$

(1 mole = 6×10^{23} molecules)

Biological oxidation:

$$\text{Carbohydrate} + O_2 \xrightarrow{\text{I}} \xrightarrow{\text{II}} \xrightarrow{\text{III}} \xrightarrow{\text{IV}} CO_2 + H_2O$$

$$\downarrow \quad \downarrow \quad \downarrow \quad \downarrow$$

CEB CEB CEB CEB

(chemical energy bundles (CEB) and some heat, totaling 110,000 cal/mole)

where I, II, III, and IV represent a stepwise oxidation of carbohydrate to trap the energy in small bundles.

Carbon dioxide and water formed in the oxidation or combustion of carbohydrate may be regarded as compounds with an energy content of 110,000 calories per mole less than that of carbohydrate. To reconvert these low-energy compounds, CO_2 and H_2O, back to carbohydrate clearly requires 110,000 calories. This may be supplied by sunlight through the agency of green plants, which contain chlorophyll capable of absorbing, and making use of, the energy of visible light. This process of combining CO_2 and H_2O and light to form carbohydrate and O_2, under the photocatalytic influence of chlorophyll, is photosynthesis. It is one of the many answers given by nature to Newton's Query . . . "may not Bodies receive much of their activity from the Particles of Light which enter into their Composition?"

The investigations in the present century as to how much light is coupled with CO_2 and H_2O to form carbohydrate, and how the coupling takes place, have had a classic history and development. First, one may profitably recall Newton's views on the nature of light, as expressed in Query 29 of *Opticks,* "Nothing is more requisite for producing all the variety of Colours than that the Rays of Light be Bodies of different Sizes." In 1900 Planck developed his quantum hypothesis of the nature of radiation, and re-expressed Newton's "Sizes" in terms of energy content. He postulated that light is composed of discrete units, called quanta, whose energy content depends on the wavelength, or color, of the light. Thus, red light of wavelength 660 mμ has been found to contain approximately 43,000 calories per mole quanta (1 mole quanta = 6×10^{23} quanta), and blue light of wavelength 430 mμ to contain approximately 66,000 calories per mole quanta.

In 1911 Einstein, with the stimulus provided a few years earlier by Emil Warburg, extended

Planck's quantum theory to photochemistry and advanced the hypothesis that in photochemical reactions quanta of radiation act as units and do so only when possessed of a given minimum energy content: chemical substances affected by light must react through the precise equality of one molecule altered per one quantum of minimum energy content absorbed. This law of photochemical equivalence, first experimentally demonstrated by Emil Warburg a few years later, would indicate that, in order to produce carbohydrate and oxygen gas from carbon dioxide and water directly in one photochemical reaction, it would be necessary to employ a quantum of an energy content of at least 110,000 calories per mole, or radiation of wavelength approximately 260 mμ, which is far outside the visible, in the ultraviolet region. If quanta were provided containing less than this energy content—for example, 90,000 calories per mole—then the reaction could not take place regardless of how many quanta were absorbed. The law also indicates that even if each quantum contained more than 110,000 calories per mole—for example, 200,000 calories—still only one molecule of CO_2 would be converted into carbohydrate per quantum of light absorbed. Because of the discrete nature of quanta, any extra calories would be wasted as heat, instead of being converted into chemical energy. The efficiency calculated on a caloric basis would thus fall below 100 per cent, although calculated on a quantum basis it would remain unity —that is, the ratio "O_2 produced/quanta absorbed" would remain one.

The question thus arises as to how photosynthesis in plants can take place at all in visible light where the quanta have an energy content of at least as low as 43,000 calories per mole, in the case of red light. If the law of photochemical equivalence holds, this can only mean that there must be several primary photochemical reactions, identical or otherwise, each requiring a quantum of energy content no more than 43,000 calories per mole. At least three (110,000/43,000) single quantum reactions would then be required theoretically—in fact, possibly many more. The establishing of the least number of quanta needed under optimum experimental conditions has involved prolonged and extensive investigations extending over the past three decades.

Otto Warburg, director of the Kaiser-Wilhelm Institute for Cell Physiology, Berlin-Dahlem, Nobel prize winner, and one of the world's most accomplished biochemists, was the first to make determinations of the quantum efficiency of O_2 production.[1] His experiments were carried out with the common unicellular green alga *Chorella*. Thirty years ago Warburg reported that no more than four quanta of red light, each containing only 43,000 calories per mole, were needed to produce one molecule of oxygen under favorable conditions, notably, *low* intensities of light and in acid media. This corresponded to a startlingly high caloric efficiency of $100 \times 110{,}000/(4 \times 43{,}000) = 65$ per cent. No other energy-requiring photochemical process with such a remarkable efficiency has been found to occur before or since. Only one other photochemical reaction is known to have an over-all efficiency even approaching that of photosynthesis, namely, the ozonization of molecular oxygen by one quantum of the wavelength 207 mμ ($3\ O_2 + 1$ quantum $= 2\ O_3$), with a maximum efficiency of $100 \times 68{,}000/137{,}000 = 50$ per cent, as first found by Emil Warburg, father of Otto. The exceptionally high efficiency of photochemical ozonization was obtained, however, with quanta of the high energy of 137,000 calories per mole in the far ultraviolet, whereas the high efficiency of photosynthesis is obtained with quanta of the low energy of 43,000 calories per mole, in a reaction that thermodynamically requires at least three such quanta (112,000/43,000).

There are relatively few nonphotochemical biochemical processes which occur with the high efficiency of photosynthesis, but one very important instance that may be cited is the formation of so-called energy-rich organic phosphate compounds from inorganic phosphate at the expense of the energy of oxygen consumption. Here the free energy efficiency may attain 60 per cent. In the nonliving world most mechanical devices are considerably less efficient. Gas turbine engines are among the most efficient of man-made machines, but they rate at best only about 30 per cent efficiency in converting fuel into work energy. The relative importance of Warburg's early discovery of the enormously high efficiency of photosynthesis under suitable conditions cannot, therefore, be overestimated.

However, on the surface at least, the four-quanta requirement still failed to harmonize with the law of photochemical equivalence, except insofar as it had also been found that the quantum efficiency was independent of the wavelength of light, as, according to the law, it should be. Within experimental error, the same quantum efficiency was found in the red, yellow, green, and blue, which means, of course, that the caloric efficiency has to decrease in this order, as the energy content of the quanta increases from 43,000 calories per mole in the red to 66,000 in the blue. Warburg discussed

the theoretical implications of his early experiments with Einstein, and they agreed at that time that the experiments were of such a nature that they did not lend themselves to a final rigorous theoretical understanding, since no other photochemical reaction was known that, when related to a single molecule, required more than one quantum. Einstein asked Warburg to reconsider the matter with him should he ever succeed in finding an underlying one-quantum process such as both men intuitively felt must occur.

For fifteen years Warburg's quantum requirement of four was widely accepted. Beginning in about 1935, however, theoretical objections were raised, because attempts to postulate a detailed chemical mechanism by which one molecule of carbohydrate could be formed even with as few as four quanta continued to prove unsuccessful in the light of the then known biochemistry. Whereas Einstein in 1923 had looked for some minimum quantum requirement of much less than four, later theoreticians came to insist upon a minimum quantum requirement of much more than four. On the heels of their objections came apparently substantiating experiments to back them up. Several groups of workers, in attempting to repeat Warburg's experiments, were either unable, or thought they were unable, to obtain the high efficiencies found by Warburg. Their results suggested an over-all quantum requirement of at least 10–20 or even considerably higher, as opposed to Warburg's finding of four. Warburg's results eventually came to be considered, by most of the workers in the field, as much too good to be accepted, as testified to by an extensive and impressive literature.

In 1948 Warburg accepted an invitation to come to the United States and work with an American photosynthetic team at the University of Illinois, for the purpose of resolving the experimental aspects of the quantum problem once and for all. His six-month appointment at Illinois ended, however, without any agreement as to what constitutes the least quantum requirement for photosynthesis. Fortunately, the Public Health Service was able to have Professor Warburg come to work for six months at the National Institutes of Health in Bethesda, Maryland. It was during this period that re-establishment of the quantum requirement of no more than four was finally effected. Substantiating data were added to the validity of Warburg's earlier findings and new techniques were developed that preclude all earlier criticisms of the experimental methods used.[2–5]

Although the four-quantum requirement was now definitely re-established, the fundamental mystery still remained, as to how four low-energy quanta could cooperate to yield high-energy carbohydrate in a manner that was in harmony with Einstein's photochemical equivalence law. If a single quantum of red light furnishes some 40,000 calories per mole, where do the missing 70,000 calories (110,000 – 40,000) come from? It was clear that some unknown principle of nature must be involved that would solve this "quantum riddle of photosynthesis" in a special manner. The answer to this riddle was finally obtained late in 1950 in continued joint investigation carried on in Berlin-Dahlem.[6–12]

It was found that, by intermittently illuminating *Chlorella* with suitably rapid alternation of light and dark intervals, one can experimentally separate the true photochemical process from the over-all photosynthetic process, and, moreover, a simple fact was discovered that had eluded all previous investigators—when the light is turned off a very large amount of oxygen over and above basal respiration disappears. When light and dark intervals were alternated every ten minutes, the customary over-all quantum requirement of three or four was observed. When, however, the intervals of light and dark were made shorter and shorter, down to the order of one minute each, the oxygen production per quantum absorbed progressively increased in the light periods, as did likewise the oxygen consumption in the dark periods, in nearly but not quite equal amounts. At least a tenfold increase in oxygen uptake in one-minute dark periods was obtained following one-minute periods of light of sufficient intensity. It thus became obvious that the actual photochemical reaction is only detectable under conditions of rapid alternation of light and dark intervals, and why it had never been observed under conditions of continuous illumination. The oxygen consumption in the back reaction prevented one from seeing the full magnitude of the forward photochemical production of oxygen. The over-all process of photosynthesis clearly consists of two different reactions which interlock cyclically, and normally hide each other. One reaction is photochemical and proceeds in the light alone, and the other is a chemical oxidation reaction that goes on not only in the dark, but as further experimentation showed, in the light also.

Now, most interestingly, when the one-minute light and dark intervals were employed, and the increased oxygen uptake in the back reaction added as a necessary correction to the oxygen production in the photochemical reaction, the quantum requirement was found under optimal conditions to be *one*. That is, in the limit, for each quantum of

light absorbed one molecule of CO_2 was picked up and one molecule of oxygen was liberated. Here, at last, was the one-quantum reaction that Einstein had anticipated nearly three decades before, the long-looked-for unknown principle, the solution of the quantum riddle. Every light quantum absorbed actually accomplishes the transformation of one molecule of carbon dioxide as the theoretical concept of the photochemical equivalence law requires. At the same time, the other laws of thermodynamics, notably the first and second, are not set aside either, for the organic substance that develops in the light reaction is not kept entirely for the plant but as fast as it is produced it is burned again in part back to carbon dioxide and water in a "dark reaction." In this combustion, however, useful energy is trapped in chemical bundles, as outlined earlier in Schema A. This gain of useful energy makes it possible that in the next illumination one light quantum can again fix one molecule of carbon dioxide. The energy of the dark reaction is used to restore the catalytic plant system to its initial state.

The experimental data make it clear that for each molecule of oxygen liberated per quantum absorbed in the photochemical reaction, two thirds or more of such oxygen reacts back to yield some "two thirds" of a molecule of carbon dioxide. Thus, when a complete cyclical process has taken place, the light reaction has brought a gain of substance corresponding to the quantum energy accepted, and the dark reaction again reduces this gain back to about one third. Now it can be seen where the 70,000 missing calories come from; they are produced in the dark reaction through combustion. The energy yield in the complete cyclical process is observed to amount to at least 65–80 per cent of the absorbed red light; hence *both* phases of the cyclical process must work with a high degree of efficiency.

The results of the foregoing investigations show that in the *mechanism* or pathway of carbon-dioxide fixation in photosynthesis, water as such is not an initial reactant; otherwise a quantum containing 110,000 calories per mole would be required per O_2 produced, which is not the case. To fit the observed quanta value of 43,000, the initial reactants must involve in addition to CO_2 a substance which, unlike free or simple hydrated water, is already energy-rich to the extent of some 70,000 calories per mole, so that only one additional quantum is needed to raise CO_2 to the approximate level of carbohydrate, with liberation of equivalent O_2. The experimental data (to be given in detail later) indicate that this photosynthetic substrate must contain chlorophyll, in such form as it occurs in the plant. To such chlorophyll may indeed be attached H and OH groups that are structurally even if not energetically equivalent to H_2O. The replacement, in due course, of such H and OH groups from water must take place during the dark, restorative reaction. From the standpoint of mechanism, water enters into photosynthesis not in the light reaction, but more immediately in the dark reaction. The immediate energy for the splitting of water comes from the combustion energy of the dark reaction, as in so many reactions of general biochemistry and chemosynthesis.

We may now write the following schema of the photosynthetic cycle, in which Chl represents the chlorophyll complex before illumination and Chl′ the chlorophyll after alteration by illumination. Chl′ is restored to Chl by the back reaction, at the expense of energy derived in the chemosynthetic reaction involving consumption of O_2 and product.

SCHEMA B

Photosynthetic Energy Transformation Cycle

I. PHOTOPHASE

+1 quantum (~40,000 calories)

II. CHEMOSYNTHETIC PHASE

(Combustion; resynthesis of Chl)
(~70,000 calories)

A few amazingly simple differential equations give the clearest and most exact statement of the underlying processes.[9, 13] The three following differential equations may be integrated to yield literally scores of equations that predict and describe the rate and efficiency of photosynthesis under a great variety of conditions, as will become evident later. These differential equations express the main facts known concerning Schema B.

I. PHOTOPHASE: $$\frac{d\,O_2}{d\,t} = J\,\frac{Chl}{Chl_o} = \frac{d\,Chl'}{d\,t} \qquad (1)$$

II. CHEMOSYNTHETIC COMBUSTION PHASE:

$$\frac{d\,Chl'}{d\,t} = -\,k\,Chl' \qquad (2)$$

$$d\,O_2 = E\,d\,Chl' \qquad (3)$$

where J is the unit number of quanta (cmm) absorbed per unit time t (minutes), O_2, Chl, and Chl′ are likewise expressed in cmm (1 cmm = 2.7×10^{16} quanta or molecules, respectively), and Chl_o = Chl + Chl′. Only light that strikes Chl is converted to chemical energy to produce O_2; light that strikes Chl′ is wasted as heat. In the back reaction, k is a (first order) rate constant dependent upon temper-

ature, and E may be defined as the fraction of O_2 required to restore the system to its initial state (including Chl′ → Chl).

The publication of these results in 1951 represented a climax in the history of the field of photosynthesis. The outstanding problem underlying the quantum mechanism, which had baffled both Einstein and Otto Warburg over a quarter of a century ago, was solved.

Some Technical Consequences of the Photosynthetic Cycle

In the preceding section of this paper we have been concerned with the maximum efficiency (minimum quantum requirement) of photosynthesis under the best possible conditions, involving low or, at most, moderate light intensities. In this section we shall deal with the more practical problem of the rates and efficiencies of photosynthesis at *very high* light intensities, and the marked effects of high-speed intermittent illumination (rapid alternation of light and dark periods). It is necessary to treat these problems mathematically in order to integrate the various opposing influences that operate simultaneously; the calculus of Newton, like his *Opticks,* is unavoidable.

Whereas, in continuous illumination of low intensities there is a direct relationship between the oxygen produced and the quanta absorbed (quantum efficiency), at high light intensities this relationship is masked, since an overwhelming number of quanta are absorbed and wasted as heat, because the system, now overtaxed, can no longer utilize them. A direct measurement of the quantum efficiency at high intensities of continuous light thus bears only a very indirect relationship to the quantum efficiency of the underlying photochemical process. At high light intensities where the rate-limiting reaction is the dark back chemical reaction, the observed quantum requirement is only the manifestation of a very inefficient machine, and is, in absolute terms, of almost no interest. However, we shall show that maximum yields can be obtained even at high light intensities if the proper type of intermittency is employed.

In order to understand quantitatively the true significance of the photochemical mechanism at saturating light conditions, it is advantageous to employ the following integrated Equation (4) that can be derived from the differential Equations (1), (2), and (3). Equation (4) applies to the constant *steady-state* rate attained after an induction period that lasts no more than several minutes after the illumination schedule is begun, whether the schedule be continuous or intermittent in character. If ΔL is time of a light period in minutes, and ΔD similarly of a dark period when the intermittent illumination is employed, then the cmm of O_2 produced *per minute of light time* is, for any intensity of absorbed light (J) and any value of ΔL or ΔD,

$$\frac{\text{cmm } O_2}{1' \text{ light time}} = \frac{J\,(1-E)}{1+\frac{J}{k\,\text{Chl}_o}} \left\{ 1 + \frac{\frac{J}{k\,\text{Chl}_o}}{k\left(1+\frac{J}{k\,\text{Chl}_o}\right)} \right.$$

$$\left. \frac{\left[1-e^{-k\,\Delta D}\right]\left[1-e^{-k\left(1+\frac{J}{k\,\text{Chl}_o}\right)\Delta L}\right]}{\Delta L\left[1-e^{-k\left(\Delta D+\left(1+\frac{J}{k\,\text{Chl}_o}\right)\Delta L\right)}\right]} \right\} \qquad (4)$$

The quantum requirement, $1/\phi$, is given by simply

$$\frac{1}{\phi} = \frac{J\,\Delta L}{\text{cmm } O_2}. \qquad (5)$$

In order to make practical use of Equation (4), let us consider various limiting cases. In continuous light, where $\Delta D = 0$,

$$\frac{\text{cmm } O_2}{1' \text{ light time}} = \frac{J\,(1-E)}{1+\frac{J}{k\,\text{Chl}_o}}. \qquad (6)$$

If one plots the rate of O_2 production against J, one obtains the rectangular hyperbola of the type illustrated in Figure 1. Here for simplification we have plotted as ordinate "cmm O_2/1′ light/*cmm*

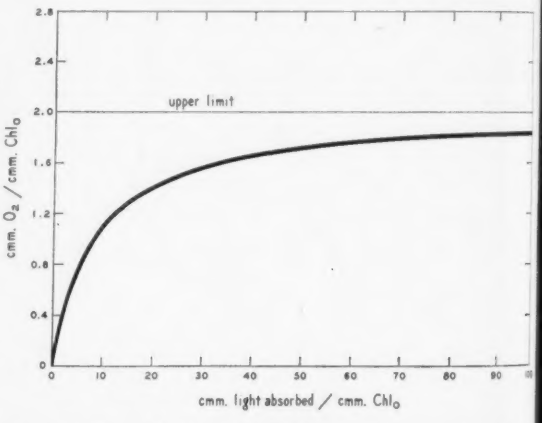

FIG. 1. Hyperbolic relation between oxygen produced and light absorbed per minute.

Chl_o" in order to express the results more conveniently in terms of unit Chl_o quantity (cmm). In this graph, k is 8 reciprocal minutes (8 min^{-1} = 8/60 sec^{-1}), which means that the average time for conversion of Chl′ to Chl $t_{\frac{1}{2}}$ = 2.3 log (2/1)/8 = 0.086 minute, or 5.2 seconds, and the time for 90 per cent completion of the back reaction is $t_{.9}$ = 2.3 log (10/1)/8 = 0.288 minute or 17.3 seconds, and, similarly, twice as long for 99 per cent completion. E is .75, so that $1/(1-E) = 4 = 1/\phi$, the quantum

requirement at low light intensities where the rate of O_2 production is virtually proportional to the light intensity, and where the thermal rate of the back reaction (conversion of Chl′ to Chl) is sufficiently rapid, relative to the forward light reaction, to convert any Chl′ formed back to Chl fast enough to prevent any quanta from being absorbed by Chl′ and hence wasted as heat. Here, Equation (6) reduces to

$$\frac{\text{cmm } O_2}{1' \text{ light time}} = J\,(1 - E). \qquad (7)$$

At about 0.5 on the ordinate scale (one fourth the maximum rate of 2), the curve begins to bend quite noticeably, signifying that the O_2 production per unit of light (i. e., the efficiency) begins to fall off as the back reaction now begins to become limiting. This bending continues up to the limit of the "light saturation" rate, where the ratio Chl/Chl_0 becomes very small, and the ratio Chl'/Chl_0 approaches unity, and Equation (4) reduces to

$$\frac{\text{cmm } O_2}{1' \text{ light time}} = k\ Chl_0\,(1 - E). \qquad (8)$$

Per unit amount of Chl_0 (1 cmm), this rate is surprisingly uniform in nearly all plants. The continuous saturation rate of photosynthesis at very high light intensities (and CO_2 concentrations) as reported in the literature for *Chlorella* is of the order of 2 cmm O_2/minute/cmm chlorophyll at 25° C. In their extensive classic work with a great variety of higher green plants of different ages and physiological conditions, Willstaetter and Stohl[14] found values ranging almost entirely between 2 and 6 cmm of O_2/minute/cmm chlorophyll at 25° C.

The constants in the curve of Figure 1 are most readily determined by plotting reciprocal of rate against reciprocal of light intensity,[15, 16] as illustrated in Figure 2. The slope of the line $1/(1 - E)$ gives directly the true quantum requirement of the photosynthetic cycle over the whole range of light intensity; the masking by the high light intensity referred to earlier is eliminated in this type of plot. The ratio of the slope/intercept is $k\ Chl_0$. The determination of k and E in the manner indicated in Figures 1 and 2 is possible because these graphs are based not only on knowledge of amount of chlorophyll but also in particular upon knowledge of the absolute units of light absorbed (J). Virtually all "light intensity" curves in the literature have been made with relative incident light intensities, and without indication of chlorophyll content, and so do not lend themselves to deriving stoichiometric relationships between reaction participants. In general, under optimum conditions, E lies between about .70 to .80 in acid medium (ϕ = .3 to .2) and .88 to .92 in carbonate-bicarbonate mixture at pH 9 (ϕ = .12 to .08).

The Blackman reaction rate constant, k, is of the order of 5–20 reciprocal minutes at 25° C in acid medium. At higher temperatures, at pH 9, and in other species of algae and higher green plants, k may be severalfold greater. Much larger values of k at 25° C are, however, widely but erroneously given in the literature, ranging up to the order of 10,000 minute^{-1}, corresponding to dark times of approximately .01 to .02 second observed to be required for completion of the dark reaction in high-speed intermittent (flashing) light. This conclusion was reached by alternating periods of light and dark at high speed. For a given light period of 10^{-5} second it was noted that as the dark period was increased the rate of O_2 production per light flash increased up to a point, but that increasing the dark time beyond this point resulted in no further increase in O_2 production.[17] This maximum dark time was consequently interpreted as the time required for the completion of the dark reaction. When the observed maximum dark time was of the order of 0.01 to 0.02 second (approximately 0.0001 min), it was concluded that $1/k$ was of this magnitude, or k = 10,000 minute^{-1}. As we shall see, the significance of such dark times and the corresponding value of k must be entirely reinterpreted in the light of inevitable mathematical consequences of intermittency heretofore never worked out. The results of such a mathematical analysis suggest that it should be possible to develop not only laboratory but eventually practical methods for obtaining high efficiencies of photosynthesis at high light intensities.

If the maximum dark time does not yield the value of $1/k$, what does it give? Before we can answer this, the concept of maximum dark time

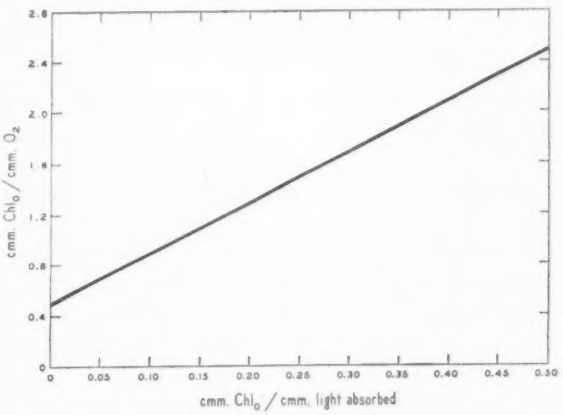

FIG. 2. Linear relation between reciprocal of oxygen produced and reciprocal of light absorbed.

must be more closely defined, since in theory (*cf.* Fig. 1), although there is a maximum rate of oxygen production per light minute which cannot be exceeded no matter how long the dark period, there is, strictly speaking, no maximum dark period. Consider the rate of oxygen production in continuous light, say $O_{2(\Delta D=0)}$, and the rate for any specified dark period ΔD, say $O_{2\Delta D}$. Call their ratio $R_{\Delta D}$.

$$R_{\Delta D} = \frac{O_{2\Delta D}}{O_{2(\Delta D=0)}}. \qquad (9)$$

Then $R_{\Delta D}$ has a maximum value, say $R_{\max}$. We may then define the dark period ΔD precisely by reference to the relationships between $R_{\Delta D}$ and $R_{\max}$. The relationship we shall use is the ratio

$$\frac{R_{\max} - R_{\Delta D}}{R_{\max} - 1}.$$

If we select a dark time, ΔD, for which this ratio has the value 0.63 (more exactly, $1 - e^{-1}$), then this dark time (which we shall refer to as the 63 per cent dark time) is exactly

$$\Delta D_{.63} = -\frac{1}{k} \log_e \frac{1 - 0.63}{1 - .63\, e^{-k\left(1 + \frac{J}{k\ \mathrm{Chl}_0}\right)\Delta L}}.$$

Now suppose one has so high a light intensity that

$$e^{-k\left(1 + \frac{J}{k\ \mathrm{Chl}_0}\right)\Delta L}$$

can be treated as equal to zero (saturation/flash). Then ΔD so defined is equal to $-\frac{1}{k} \log_e (1 - 0.63) = \frac{1}{k}$. The 63 per cent dark time is thus equal to $1/k$ if and only if one has saturation per flash. Consider now the other extreme, in which light intensity is so low that $e^{-k\left(1 + \frac{J}{k\ \mathrm{Chl}_0}\right)\Delta L}$ can be treated as equal to unity. (With ΔL as low as 10^{-5} second, as in some work,[17] this would be true even with an extremely high value for J.) Then the 63 per cent dark time is equal to

$$-\frac{1}{k} \log_e \frac{1 - 0.63}{1 - 0.63} = 0.$$

The 63 per cent dark time observed may consequently vary from zero to $1/k$, its value depending entirely upon the amount of light given per flash. Only with saturation per flash can the observed dark time be equated to $1/k$, and in practice this condition has never been realized in previous work, all statements to the contrary notwithstanding.

In high-speed intermittency or flashing-light experiments, in which ΔL and ΔD are small (fractions of a second), Equation (4) reduces to

$$\frac{\text{cmm } O_2}{1' \text{ light time}} = \frac{J(1 - E)(1 + \Delta D/\Delta L)}{\frac{J}{k\ \mathrm{Chl}_0} + (1 + \Delta D/\Delta L)}. \qquad (10)$$

At low values of J this reduces again to $J(1 - E)$, as in continuous light, so that intermittency results in no improvement in yield at low light intensities. At sufficiently high values of J, however, Equation (10) becomes

$$\frac{\text{cmm } O_2}{1' \text{ light time}} = k\ (1 - E)\ \mathrm{Chl}_0\ [1 + \Delta D/\Delta L]. \qquad (11)$$

Since the rate in continuous light of saturating intensity is, from Equation (8), $k(1 - E)$ Chl_0, intermittency here results in an improvement in yield equal to $k(1 - E)$ Chl_0 $(\Delta D/\Delta L)$, or, on a percentage basis, $100(\Delta D/\Delta L)$ per cent over the continuous light yield. Thus, with $\Delta D/\Delta L = 1$, a maximum limit of 100 per cent improvement in yield per unit of light would be obtainable at the highest light intensities, as first observed experimentally by Warburg in 1919.[1] With $\Delta D/\Delta L = 4$, the limit would be 400 per cent, as approximated by Emerson and Arnold in 1932[17] experimentally, without knowledge of the mathematical inevitability involved. So long as ΔD and ΔL are sufficiently small (the intermittency sufficiently rapid), there is no limit to the increase in yield per unit light that can be attained up to $(1 - E)$, no matter how high the light intensity. Also, no matter how high the light intensity used, one can always select an intermittency (always provided that ΔD and ΔL are sufficiently small) that will give a quantum yield that approximates $(1 - E)$ as a maximum. As can be seen from Equation (10), the quantum yield for any J and any such intermittency is

$$(1 - E) \text{ times } \frac{\left(1 + \frac{\Delta D}{\Delta L}\right)}{\frac{J}{k\ \mathrm{Chl}_0} + \left(1 + \frac{\Delta D}{\Delta L}\right)}.$$

By taking $\Delta D/\Delta L$ sufficiently large the second factor can be made to approach unity, no matter how high J.

The ratio $\Delta D/\Delta L$ can thus be varied so that for any light intensity one can obtain a maximum yield $(1 - E)$, provided that the cycle of intermittency is sufficiently small. The same yield, $(1 - E)$, could be obtained at a given value of J by interposing a neutral filter whose transmission is $\Delta L/(\Delta L + \Delta D)$.

On the other hand, if the ratio $\Delta D/\Delta L$ is such that a yield poorer than $(1 - E)$ is obtained then, correspondingly, a neutral filter whose transmission is $\Delta L/(\Delta L + \Delta D)$ would give the same poorer yield. This relationship between neutral filters and high-speed intermittency holds for all portions of the light intensity curve. Thus, for example, the O_2 production with a one to three sector $(1\ \Delta L/3\ \Delta D)$ rotating at sufficiently high speed approaches the O_2 production obtained with a neutral filter whose

transmission is 25 per cent $[\Delta L/(\Delta L+\Delta D)] = 1/(1+3)$. In the limit, high-speed intermittency effects in time what a neutral filter does in space, or, as adumbrated by Newton (*Opticks,* Defin. I), "Light consists of parts both Successive and Contemporary, because in the same place you may stop that which comes presently after; and in the same time you may stop it in any one place, and let it pass in any other."

The number of chlorophyll molecules in the photosynthetic unit. In the aforementioned flashing-light experiments in which the light flashes were extremely short (10^{-5} sec) compared to the dark periods taken for completion of the dark reaction, it had also been calculated that approximately 2,500 chlorophyll molecules were involved in the production of one molecule of oxygen.[17] These calculations were based on the assumption that enough light had been given per flash to saturate the photosynthetic process, and, when sufficient dark time was allowed between flashes, the output of O_2 was supposed to have given the maximum ratio of O_2 produced per molecule of chlorophyll. In these experiments, however, saturating light intensity was not clearly demonstrated, and later experiments[18] definitely showed that saturation was, indeed, far from attained. One has only to recall the explanation of high-speed intermittency in terms of neutral filters to understand the result. In these experiments, the rate of O_2 production per time elapsed was only about one sixth that of the rate in saturating continuous light. This means, in terms of continuous illumination, that the total light supplied per time elapsed during the intermittent illumination was insufficient to exceed the light-limiting portion of the intensity curve; the same result could have been attained with a neutral filter of about $\Delta L/(\Delta L+\Delta D) = 10^{-5}/(10^{-5}+10^{-2}) = 10^{-3}$ transmission. Calculations based on these considerations indicate that in each flash only 1/250 of the chlorophyll molecules were hit by, and absorbed, quanta. The suggested chlorophyll unit of 2,500 chlorophyll molecules/O_2 molecule produced has prevented both theorists and experimentalists from discovering the true stoichiometric relationship of chlorophyll to O_2 production, and is devoid of fundamental physical significance. As a result, the various explanations of the observed ratio in terms of a large "photosynthetic unit," limited number of reducing centers, or insufficient stabilizing enzymes (inefficient back reaction) are thus irrelevant and must be discarded. The apparent photosynthetic unit observed, of the order of 2,500 molecules of chlorophyll, is an artifactual expression of highly inadequate light provision per flash, which provision should have been at least a hundred times greater for true (greater than 95 per cent) saturation in each flash. With sufficiently high light absorption (J), the required dark times would have been of the order of 5–10 seconds. We have found experimentally in intermittent as well as in continuous illumination that the maximum ratio of chlorophyll to oxygen produced actually can approximate 1 or 4, depending upon whether one is considering the photochemical process or the over-all cyclic process, as will be indicated.

As one can see in our differential and integrated equations, the amount of chlorophyll has been employed as a variable. This is by no means arbitrary, although no proof has been presented up to this point of its actual stoichiometric relationship to O_2 production in photosynthesis. One might justly qualify the significance of the aforementioned k value of the order of 5–20 minute^{-1} in view of the fact that this value depends in our various equations on the amount of chlorophyll. Because of this fact a method for determining k which did not involve knowing the amount of chlorophyll was required. Such determinations were carried out by two different procedures. First, k was estimated as to order of magnitude by bringing cells to compensation of respiration (zero pressure change) with diffuse white light, then illuminating for 1–3 minutes with a known added amount of light of an intensity that gave a maximum quantum requirement of $1/(1-E) = 4$ for the over-all cycle when it was completed; then turning the light off, and following the time course (decay curve) of the back dark reaction in an approximate manner, limited by manometric equilibration times. The equation for the amount of O_2 produced by any time, t, during a light interval of duration ΔL is $(t = \Delta L)$,[9]

$$\text{cmm } O_2 = J(1-E)\,t + \frac{EJ}{k}(1-e^{-kt}), \qquad (12)$$

whereas the O_2 present after any time ΔD of dark is[13]

$$\text{cmm } O_2 = K\,e^{-k\Delta D}, \qquad (12')$$

where K is the value of (12) at the end of the light period—i.e., Equation (12) with ΔL substituted for t. Observations made in connection with Equation (12′) gave k values ranging between 2 and 20 minute^{-1}. Such a determination of k is independent not only of the knowledge of amount of chlorophyll but does not require the use of saturating light, nor indeed is this desirable. The same may be said of the following more accurate, analytical method that was then worked out on an entirely different procedure.

From Equation (4) an implicit solution for k

was derived which did not involve an actual knowledge of the amount of chlorophyll, except insofar as was contained in the expression k Chl_o, which group term could be evaluated by several methods, one of which is illustrated in Figure 2, provided J is known (which it should be in nearly every good experiment nowadays, since suitable actinometers[7, 11, 12, 19] have become available). The implicit equation is

$$k = \frac{\frac{J}{k\ Chl_o}\left\{1 - e^{-k\left(1+\frac{J}{k\ Chl_o}\right)\Delta L}\right\}}{(R-1)\left(1+\frac{J}{k\ Chl_o}\right)\Delta L},$$

$$\text{where } R = \frac{O_2(\text{cmm/min}) \text{ with adequate } \Delta D \text{ (intermittency)} = J(1-E)}{O_2(\text{cmm/min}) \text{ in continuous light}}. \qquad (14)$$

The experimental problem was to evaluate R, which was done in the following manner. A light intensity was chosen on the intermediate bending portion of the intensity curve (Fig. 1) that yielded $1/\phi = 10$ in continuous light. Flashes of this light were given for one-second duration, and quantum requirement determinations were made with increasing dark times until the light per flash gave a limiting yield of $1/\phi = 4$. R was evaluated from Equation (14) by using the rates of oxygen production per minute of light time for the conditions $1/\phi = 4$ and $1/\phi = 10$, giving in such an experiment a value of 2.5. If the data of the experiment just described were plotted in the form $1/O_2$ against $\Delta L/(\Delta L + \Delta D)$ = fraction of light time, then the slope $1/k(1-E)$ Chl_o divided by intercept $1/J(1-E)$ gave J/k Chl_o. When R, J/k Chl_o, and ΔL were substituted in the equation, the implicit solution for k yielded values between 5 and 20 minute^{-1}. The agreement in the k determinations by the methods dependent upon a knowledge of the amount of chlorophyll and the methods requiring no knowledge of the amount of chlorophyll clearly shows a simple stoichiometric relationship of the order of 1:1 between molecules of chlorophyll and molecules of O_2 produced in the photochemical process, and thus of 4:1 in the over-all cycle under optimum conditions. What could be simpler than that nature, in harmony with Einstein's photochemical equivalence law, has one molecule of chlorophyll absorb one quantum of light to reduce one molecule of CO_2 and produce one molecule of O_2?

The foregoing technical account of conditions necessary for maximum efficiency at both high and low light intensities presents many interesting possibilities for practical application. Engineering methods of food production may be developed to make far more efficient use of solar radiation by utilizing some form of intermittent illumination along lines suggested in this report. For example, if one wished to produce a food crop of algae one might design a flow system that would pass the algae in and out of continuous sunlight of high intensity, and in this way increase the algal production per unit of light by a type of intermittency provided by the moving algae themselves, which would obviate the necessity of turning light on and off or of wasting continuous light during blocked-off dark periods. Also, it may be that a thorough investigation of the characteristics of the rate constant k of the dark (Blackman) reaction that limits the rate of photosynthesis at high light intensities (such as it often does under conditions of bright sunlight) might yield methods for markedly increasing k. This, in turn, would allow one to increase the crop production per acre in nearly the same proportion as k could be increased.

An understanding of the basic mechanism of photosynthesis holds promise not merely of increasing food production per unit of light, but of the utilization of solar energy in many other ways as well. Thus, if the photosynthetic process by which low-energy quanta are combined to yield high-energy carbohydrate were simulated, it might be possible to break water down directly to hydrogen gas with sunlight. Such a process would eliminate mankind's present dependence on exhaustible supplies of natural gas for energy, and would substitute a photochemical process giving hydrogen gas that could be made in any part of the world possessing water and sunlight. Similarly, now that the forward photochemical reaction in photosynthesis is definitely known to be a one-quantum process, a theoretical investigation of the direct conversion of sunlight to electricity is possible.

The laboratory fission of uranium revealed the possibility of utilizing the binding energy of the atom. Basic understanding of the photosynthetic mechanism at the laboratory level may open new possibilities of utilizing another vast and largely untapped source of energy—sunlight.

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Out of the trees and the starlight that the river of time has whirled,
The mind has grappled for meaning on the highways of the world.
His is the wind and the plover, the sand that the ocean wets,
The work of the forest and mountain, the sun on the spider nets.

So think of it never as ended, burned for a moment's space
But fed on the thrust of the river and the lightning's veering trace.
Mind is as real as the dawnlight, and the sound in the ocean's shell—
The blood, the urge, and its thoughts that have known the cosmic spell.

Bearing the eternal thunders in the meshes of a brain,
One goes as the strong in awareness, to speak of the flower and the rain.
He counts the good and the bitter; he feels the sky's new thrust,
And he is the rock and the thistle, the voice that is risen from dust.

Daniel Smythe

The Fibonacci Series

JOHN CRAWFORD PIERCE

The author is a graduate of Middlebury College and of Syracuse University. He has been a public school teacher in Connecticut, Massachusetts, and Vermont, a metallurgist for Jones & Lamson Machine Tool Company, and is now professor of natural science at Goddard College. Extracurricularly, he served on the Vermont Committee for Stream Purification and is still interested in that field. He is a past president of the Vermont Mineralogical Society.

SOMETIME before the year 1220, an inspired Italian mathematician stumbled onto a series of numbers the full implications of which are still being uncovered. Our hero bore the various names of Fibonacci, Leonardo of Pisa, and The Blockhead. The Fibonacci series is no more than a simple little doodle with numbers, yet it holds some rather piquant truths, important to a wide range of men. These range from artists, botanists, and designers to yachtsmen, Yalemen, and zoologists.

The mathematics of the early thirteenth century presents a strange mixture of practicality and impracticality. Much of what Fibonacci did was impractical, being mainly concerned with the relations of numbers with each other, rather than with the application of mathematical principles to everyday problems. One of the few times he asked himself a practical question, his answer hit the very jackpot of practicality, touching as it does so many fields, as will be apparent. He asked, "How many rabbits will result in a given time from one normally prolific pair, if we know the length of each generation?" The old manuscripts do not tell us whether his answers checked experimentally. In those days, the best brains did not indulge in experiment, preferring to leave that sort of thing to the rabbits. But in order to arrive at his hypothetical answer, he set down a series like this:

1	plus	1	equals	2		13	plus	21	equals	34	
1	"	2	"	3		21	"	34	"	55	
2	"	3	"	5		34	"	55	"	89	
3	"	5	"	8		55	"	89	"	144	
5	"	8	"	13		89	"	144	"	233	
8	"	13	"	21		144	"	233	"	377,	etc.

That this apparently indefensible number-doodle is really the product of some sort of inspiration, we shall presently see. In the meantime, we take leave of Leonardo Fibonacci Pisano himself. He really had something there but, like the Norse discoverers of America, he didn't know it.

We shall build on the simple Fibonacci series a mathematical structure, following a long line of his successors. The chronology of this development since 1220 is complicated, so we shall select only those parts that will advance the idea here being considered. If we set up the terms of this series as ratios, or fractions, and put them into two columns, alternately, and express the results as decimals, we get this:

(1)	$\frac{1}{1}$	equals	1.000000	(2)	$\frac{1}{2}$	equals	.500000
(3)	$\frac{2}{3}$	"	.666667	(4)	$\frac{3}{5}$	"	.600000
(5)	$\frac{5}{8}$	"	.625000	(6)	$\frac{8}{13}$	"	.615385
(7)	$\frac{13}{21}$	"	.619048	(8)	$\frac{21}{34}$	"	.617684
(9)	$\frac{34}{55}$	"	.618182	(10)	$\frac{55}{89}$	"	.617978
(11)	$\frac{89}{144}$	"	.618056	(12)	$\frac{144}{233}$	"	.618026

Now, you see the results in the first column geting smaller and smaller, whereas the results in the second column get larger and larger. They seem to be tending toward some number as a meeting place. If we took enough terms of the series to start with, we would find that the number they are both heading for is .618034. And that number is something to conjure with.

If we draw a rectangle the sides of which are in the ratio of .618 to 1, it looks like Figure 1. (We can knock off the 34 millionths, to keep it simple.) This rectangle has several remarkable properties, both acsthetic and mathematical. It has been shown by several psychologists to be the rectangle

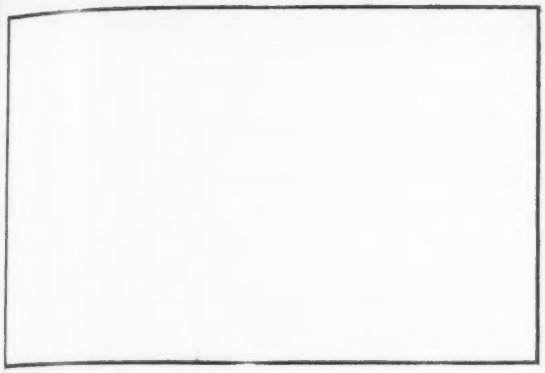

FIGURE 1.

most pleasing to the eye. Its proportions are therefore used by designers wherever practical, for everything from fireplace openings to billboards. Its mathematical peculiarities depend on the fact that the Fibonacci series can be arranged as a continuing fraction. Thus, if we made our rectangle with proportions of 1.618034 to 1, instead of .618034 to 1, we would get a figure of the same shape and proportion. From this it may be seen that 1.618034 multiplied by .618034 will give unity. Thus we lead into the next step, which is to take a perfect square out of our rectangle, and have left a rectangle of the same proportions, as in Figure 2.

You can pull that trick only on a rectangle of these proportions, and there is left always the similar remainder. It is simple, therefore, to pursue the matter until the space becomes too cramped, as in Figure 3. (Does this begin to suggest a modern linoleum floor? If so, it is because these proportions are frequently used in design.)

With one more step we can begin the discussion, as the professor puts it. We can swing a curve through all the little boxes, from the inside out, as in Figure 4. The result is a logarithmic spiral. This is but one of several ways of arriving at such a spiral, but this way was used here because of the biological importance of both the numbers and the curve.

The logarithmic spiral is one of the most basic things in nature's architecture. Longitudinal sections of many snail shells show that snails have used this plan. The chambered nautilus has, too, and goes the gastropod one better by having all his chamber walls, or septa, also on that curve. A breaking wave follows it almost exactly. Beaches with an outside curve, like Sandy Hook or Cape Cod, show it. F. H. Chapman, of the Swedish Marine, showed in 1796, that the best form for anchor arms would be sections of a logarithmic spiral joining the shank at an angle of 67½ degrees. Minute sea animals, such as the Globigerinae, are forced by their mode of growth to follow the curve, as do almost all growing things that start from a single cell, at some point. When the actual external form does not resemble the spiral, the rate of growth may be graphed on the same curve, as in bacterial increase. But it is when we get to analyzing daisies, sunflowers, and pine cones, not to mention artichokes, that we see a startling relationship between the curve and the numbers from which it is derived.

If you look closely at a sunflower head, you will see that the seeds are arranged in logarithmic spirals out from the center, and that these spirals go in both directions. The shape of the sunflower seed must accommodate itself to the space between these unwinding lines. If you were to count the number of clockwise and counterclockwise spirals, you would get numbers that are successive terms of the Fibonacci series. Why should this be? What is nature up to here? The answers are not yet completely known. Incidentally, most average sunflower heads have 34 and 55 spirals. Some are found with 21 and 34, and very small ones show 13 and 21 spirals. On the other end of the scale, it was our erstwhile friends, the Russians, who grew the biggest one. Before the war, they were experimenting extensively with sunflowers, which have some food value and several by-products, and are easy to grow. The Russians published accounts at that time of one huge head with 89 and 144 spirals—which grew without the help of Trofim Lysenko, too.

Getting back to the curvaceous flowers, daisies, asters, and their relatives with compound-headed flowers all have the same curious characteristic as the sunflower. But there is a further phenomenon shown by growing plants with equally impressive mathematical consequences. This is called by botanists "phyllotaxis," which refers to the orderly

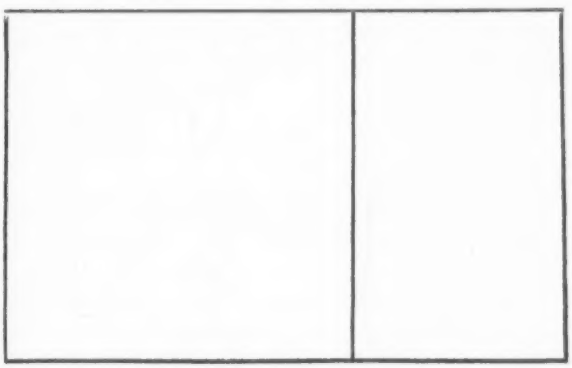

FIGURE 2.

arrangement of leaves on a stalk. If you take the stalk of a weed, or indeed of almost any green plant, you can see the way it works. Start at the base and count the number of leaves as you go up the stalk, calling the first one zero. When you come to a leaf directly over the first one, you will have some number of the Fibonacci series. Furthermore, if you count the number of times you had to go around the stalk on the way up, that number is also a member of the series. If you spiraled from left to right the first time, count the turns as you go in the opposite direction. If you get a different number, that number is also one of the series. And one of those numbers will be adjacent in the series to the number of leaves you were dealing with at first! After you have worked it out on a few simple plants, you can try it on pine cones, artichokes, head lettuce, onions, and a host of harder and more unlikely things. Well, so what?

Writing in 1880, the botanist Charles Bessey described the intricacies of phyllotaxis, with lists of the species showing the various ranks up to 144, which is seen in the interfloral bracts of *Helianthus annuus*, the Russian sunflower. But then, in a footnote, he committed an error in judgment common in those days, but rarely seen in these latter times when research seems to have a way of illuminating unintended mysteries. Bessey says:

> It is of great importance that the student should not regard these spirals as anything more than convenient means for describing any particular leaf-arrangement. Entirely too much attention has been given to working out all kinds of curious mathematical laws, which are, to say the least, absolutely worthless to the morphologist. So much has this been done, that the study of Phyllotaxis has in some quarters become little more than a species of mathematical gymnastics.

That this discouraging opinion was a mistake is shown by the researches of Jay Hambidge, who used phyllotaxis, among other things, to help rediscover an important prinicple of design that had been lost since centuries before Christ.

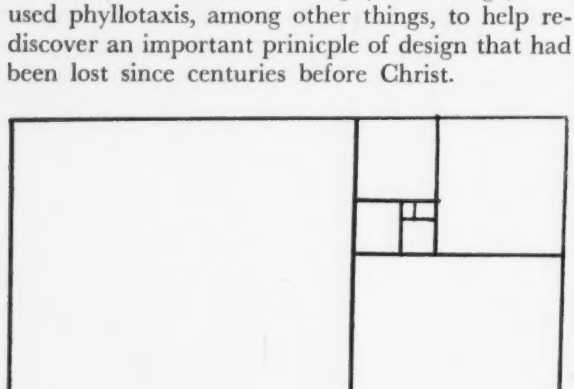

FIGURE 3.

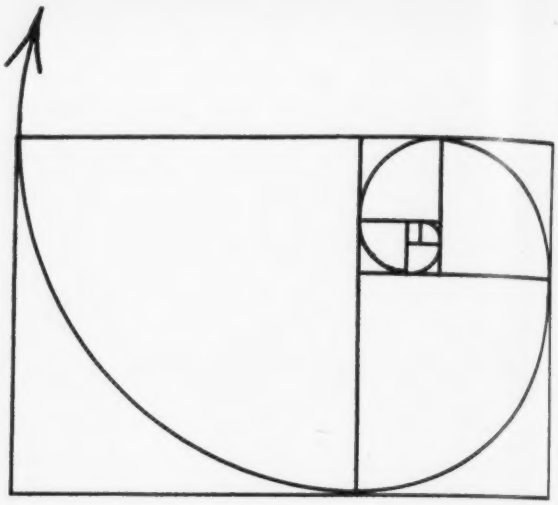

FIGURE 4.

Jay Hambidge, around 1900, doing research for the School of Fine Arts at Yale, became impressed with the apparent incoherence of what was then modern design. He was convinced that somewhere in nature he could find a correlating principle that designers and artists could use to control their composition and form. His search was a wide-ranging one, including primitive idols and Gothic cathedrals. But, since it was a natural principle he was after, he went especially to the actual "originals" found in nature, and there he found what he could use. His results took the form of just two types of symmetry, or proportion. The geometrical analysis of one had qualities of activity—loci, generating figures, and what he called "whirling squares," which were really square-including rectangles. The other form of symmetry was static. It had been employed as a basis of design since the end of the Greek classic period by everyone from Da Vinci to telephone-booth doodlers, and architects and designers had been confined to static symmetry since before Christ. The natural prototypes showing this symmetry are such things as radiolarians, diatoms and desmids, simple flowers, and their seed pods. Most mineral crystals show this static symmetry. It is probably better known among naturalists as radial symmetry. But it is the other kind, dynamic symmetry, with qualities of action and growth, that is more significant.

Hambidge found that the basis of the design of growing things like shells, flowers, and leaves was also the basis of a method of design in art. His way of arriving at this basis was both geometrical and arithmetical. We know that there was nothing new in our knowledge of this association, but when Hambidge turned to the ancient man-made designs, he made an exciting rediscovery. Having es-

tablished the analysis of dynamic symmetry, he found that this kind of design was known to only two peoples, the ancient Egyptians and the ancient Greeks. Only the Greeks had made full use of it in their art, and then the method had been lost at the end of the classic period, before Christ. Our friend Fibonacci had later stumbled onto that small part of it that bears his name. He didn't realize that he was close to something more important than amusing the court with arithmetic, and so the real rediscovery is Hambidge's.

Although Greek statues and architecture show, upon analysis, dynamic symmetry, it was in pottery that it was worked out for moderns. The analysis of enough vases, amphorae, skyphoi, and just plain pots showed a reverence for geometry on the part of the Greeks even deeper than had been suspected. By inscribing and circumscribing rectangles around the profiles of the vases, using salient features as points of reference, rectangles were obtained that resembled the .618 rectangle. Other rectangles were such that diagonals drawn through them would serve several rectangles drawn to the same profile simultaneously, locating minor features. On a simple amphora the number of crucial rectangles would be small—only two or three. On a more complicated piece of pottery like a ceremonial urn the matter would be tremendously complicated, with twenty or thirty different rectangles and diagonals—but there would always be that unity whereby one diagonal would serve several functions. A favorite place for an important feature of a piece seemed to be where two diagonals would intersect at right angles. It was this feature of favoring right angles among diagonals that gave Hambidge his clue to the basis of Greek design. Indeed, those old craftsmen were very clever, and in a way so subtle that the real basis of their design was forgotten for over two thousand years.

The development of this intricate system of design started as early as 3000 B.C. By that time there had grown up in Egypt an immensely involved system of mathematics, mainly geometry, which had arisen from the need to relocate farm boundaries each year, after the Nile flood. Obviously, between floods the men who possessed special knowledge of surveying had plenty of time to dream up further kinds of mathematical mischief. Although this pastime was rather a secret branch of religion, the mathematicians shared some of the best of it with the artisans who were carving tombs and temples, and writing poetry in hieroglyphics. Thus, a primitive form of dynamic symmetry can be detected in some of these ancient works. That the Egyptians had advanced the principle appreciably is shown by their use of the pentagon as well as the rectangle as a starting point for their diagonals for the location of eye-catching features. Then, in the sixth or seventh century B.C., the knowledge got across into Greece, and the Greeks began to develop it with inspired skill. It suited their taste for a link between nature, which they worshiped, and mathematics, which inspired their thinking, and art, through which they expressed their finer feelings.

Among other things, the Greeks became very excited over the Golden Section, which is a way of dividing a line into two parts so that the short part and the long part have the same ratio of lengths as the long part has to the whole line. (This ratio is, ideally, our old friend .618 again, but the Greeks didn't know it by that kind of number.) They erected thousands of complicated structures on the Golden Section, in triangles and rectangles. In the process they even developed the Pythagorean theorem, the basis of much of our modern mathematics. Euclid wrote book after book of propositions, and among other thinkers there was a great consciousness of proportion and design.

Plato, Euclid, and Pythagoras are some of the names we all know from that period. Their mathematics and philosophy were sound enough to stand for two millennia, even though spattered a bit by a few paradoxes. A goodly company of their less responsible followers, however, were carried away by the obvious links between nature, mathematics, and art, and have sadly gummed up the pages of philosophy with fantasy and mysticism, much of it unintelligible declarations about the Golden Section and Destiny. (These ideas were forerunners of the Eddington–Jeans–Bertrand Russell argument about God the Mathematician.) It is quite possible that this overdoing of a good idea to the point of unintelligibility led to the loss of the principle to designers of the postclassic period. But the main fact that stands is a simple one. It is merely that *the basis of good taste and aesthetic appeal is the same as the basis of nature—growth, vitality, and dynamic symmetry.*

If the shades of those old Greek designers could have followed their works of art for two millennia, from Roman palaces to French abbeys, from Continental museums to American universities, they would have chuckled into the ether, for they would have seen people through the ages really enjoy the beauty of their designs, without knowing just why they seemed so satisfactory. One can imagine that after Jay Hambidge spilled the beans, discovering that they were applying the geometry

of life itself to their pots and jugs, they might have sung a chorus and checked back in at Olympus, chanting, "Let the moderns take it from here!"

The principle has been a little slow to catch on, however. Hambidge himself tried to apply it to a wide variety of fields, on everything from sculpture and painting to furniture and type fonts. But it remains little used; it is a difficult discipline, and an artist-mathematician is a rarity. George Bellows was successful with it, and architects sometimes use it. Paul Cezanne, not knowing of it, used it unconsciously in places. Paul Feeley, at Bennington College, and Leo Katz, at Howard University, are enthusiasts for it; little by little our artists and designers may yet learn to use nature's ideal.

The realization of this ideal, used in expressing structural form, should enable the designer actually to surpass nature, by attaining what nature cannot do to minute perfection. Although nature's principles are perfect, stresses and strains in the environment lead to imperfect manifestations. The artist or designer need not be stopped by these difficulties. His result should mirror the underlying principle rather than the surface features, when the two do not coincide. So it behooves him to study nature, who would try to give it expression.

If you are neither an artist, nor a mathematician, nor a biologist, you still can indulge yourself in the psychology of aesthetics. Eugene P. Northrop, in pointing out the universality in nature of the constant .618034, asks, of its aesthetic appeal, "Is it because we, who are the judges of aesthetic appeal, are ourselves a part of Nature?" This would seem likely, and the idea ought to impress Gestalt psychologists. As for the rest of us, we can continue to relish unabashed the beauty of a wave, a flower, a weed, a shell, or even a comely figure, remembering that the unifying principle of design seen in them all is nature-built into ourselves.

SMO ON THE AIR

Station	Sponsor	Time
	Sunday	
KLBM, La Grande, Ore.	Baker-Union Department of Health (Research Report)	10:15 A.M.
	Monday	
WOI-FM, Ames, Iowa	Iowa State College of Agriculture and Mechanic Arts (Articles of Interest)	7:45 P.M.
	Tuesday	
WEVD, New York City	Wendell W. Rázim (Science for the People)	9:00 P.M.
	Wednesday	
CKPC, Brantford, Ont.	The Telephone City Broadcast Limited (Modern Science)	9:45 P.M.
	(Irregular)	
KBKR, Baker, Ore.	Baker-Union Department of Health (Research Report)	....

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Some Relics of Galileo in Florence

RUFUS SUTER

The author, whose real vocation is linguistics, is a member of the staff of the Army Map Service in Washington, D. C. His avocation is the study of the history of science, and in the course of a long vacation in Italy last year he spent some time in Florence in enthusiastic pursuit of his hobby. This article is one result.

IF A visitor in Florence is not on the trail of paintings and statuary he is likely to be regarded as wanting in taste and discernment. Yet Florence and her environs in corners seldom visited by the tourist and mentioned only vaguely by the rank and file of citizens offer also a mine of relics which have beauty for only a few, but which nonetheless represent an activity that has had wide influence on civilization. These relics are the legacy of a man who almost four centuries ago began to lay a firm foundation for modern observational, experimental, and inductive methods in science. This man, Galileo Galilei, although born in Pisa, came of Florentine stock, and throughout his life he invariably returned to Florence from other parts of Italy as if coming home. In 1616, for example, he returned from Rome, where he had spent several years discussing his telescopic discoveries in astronomy and had succeeded in calling down a warning about the danger to religion of the teaching of Copernicus. He settled on the outskirts of Florence in a villa at Bellosguardo.

A view of the villa may be had from the roof of the Observatory of Arcetri, especially if one may use a telescope. It is large and plain, an oblong block on a hilltop. While at Bellosguardo Galileo finished his unfortunate work the *Dialogo dei due massimi sistemi del mondo,* where in spite of churchly warning he set forth a defense of the Copernican system. This book was published by Landini in Florence in 1632, and it appeared fortified by the imprimatur and *nihil obstat* of ecclesiastical authority. Today's astronomers at the observatory like to show a first edition to visitors and to call attention to these signs of license in order to prove that when the book came off the press there was no prejudice against it.

Galileo's last return to Florence was when, almost seventy, he came as a prisoner to the house celebrated in poetry and history, the villa on the Via del Pian de' Giullari in Arcetri. This return was from Siena, where he had spent several weeks with a friend, Archbishop Piccolomini, after his abjuration of the teaching of Copernicus before the Inquisition in Rome. This villa is a shrine to science in a land filled with shrines to the great souls of religion.

If we climb from Florence by the steep and narrow Costa San Giorgio we will have our first hint of the esteem in which the Italians hold the maestro, for we will emerge suddenly on a broad, straight avenue lined with stately trees and named, as the signpost indicates, the Viale Galileo. This is our introduction to the quiet Florentine suburb of Arcetri, which from this vantage point is all green fields and bright open spaces, in welcome contrast to the stony confinement of the grim Costa San Giorgio and the high stone walls succeeding it. The walk from the observatory to the villa is delightful, with a view on the right over a stone wall down into a rich gully with straight furrows and luxuriant olive trees and in the distance, as far as the eye can see, rolling green hills. The Via del Pian de' Giullari is an alley characteristically shut in by crowded rows of ancient stone houses. The townsfolk say that the community is the same today as it was in Galileo's time—except for electricity. The villa itself, where the master was interned, bears in a niche on its front wall a bust beneath which is the legend:

Qvesta effigie del divino Galileo Galilei fece porre nel MDCCCXLIII Antonfilippo Marchionni.
("This likeness of the divine Galileo Galilei was placed by Antonfilippo Marchionni in 1843.")

Farther down are two words: ZYN ΘEΩ ("With God"). Then comes a longer inscription:

Aedes qvas viator intveris licet exigvas divinvs Galilaevs coeli maximvs spectator et natvralis philosophiae restitvtor sev potivs parens pseudosophorvm malis artibvs coactvs incolvit ab anno MDCXXXI Kal

Novembris ad annvm MDCXLII VI Idvs Ianvari heic natvrae concessit. . . .
("Traveler, in this sanctuary which you behold, the divine Galileo, supreme observer of the heavens and restorer or rather father of natural philosophy, was permitted to spend his last years, compelled by the evil devices of pseudosophers, from the Kalends of November 1631 until VI Ides of January 1642. Here he died.")

Because of a housing shortage the villa is at present, appropriately, occupied by an astronomer of the Observatory of Arcetri.

It would be an exaggeration to describe Galileo's life in this pleasant community as strict confinement. He regularly visited his daughter, Sister Maria Celeste, at the convent of San Matteo, now a monastery, within walking distance of the villa. But if the old man began his internment in 1631 he had little time with his daughter, for she died in 1634. He traveled occasionally to visit his son, Vincenzio, on the Costa San Giorgio. At the villa he wrote the book that subsequently proved the most valuable of his treatises: the *Dialoghi delle nuove scienze,* published by the Elzevirs in Leyden in 1638. The *Dialoghi* was the final setting forth of his intuitions, mathematical deductions, and experiments in mechanics. A few months before his death, and several years after he had become blind, Evangelista Torricelli, inspired by the reading of this book, came to the villa to be his clerk. The sympathetic understanding of this gifted youth, who afterward became one of the classical physicists, brought joy to the heart of the aged master. In these last months, also, Vincenzio Viviani, a Florentine boy still in his teens, acted as another son to him. Viviani was a geometer, but he is remembered chiefly as the first biographer of Galileo.

Although the master's relics are now in the Museum of the History of Science, they were previously kept in a hall called the Tribuna di Galileo in another Florentine museum, the Museo di Fisica e Storia Naturale, near the Pitti Palace. This hall was a magnificent memorial. Intended to commemorate the father of experimental philosophy, it was the creation of the best Tuscan artists. The architect, Giuseppe Martelli, was a Tuscan. The marble is Tuscan. There were frescoes, reliefs, medallions, busts, a statue, inscriptions, and exquisite ornamentation, all in marble, ivory, ebony, and gold; and original instruments of the maestro himself, of his disciples, and of members of the learned society the Accademia del Cimento, a Florentine analogue of the Royal Society of London. The memorial was conceived by the Grand Duke Leopoldo II, of the House of Hapsburg-Lorraine, which succeeded the Medici as rulers of Tuscany, and it was finished in 1861 under the auspices of Vittorio Emanuele II, first king of Italy.

The young Galileo discovering the law of the isochronism of the pendulum. Fresco by Luigi Sabatelli at the Tribuna di Galileo, Museum of Physics and Natural History, Florence.

Today the Tribuna is empty except for Costoli's tall statue of Galileo, and the frescoes. The doors are kept locked, but one will find it worth while to go to the trouble of making arrangements with the museum officials to gain access. The statue is impressive for the square and noble forehead turned toward the sky. The maestro is represented as standing, to symbolize that the new experimental approach to nature is a practical one, not mere armchair speculation. The frescoes are certain to fascinate the student of the history of science. One of them, by Luigi Sabatelli, depicts Galileo as a boy watching the swinging lamp in the Cathedral of Pisa. Another by the same artist represents Galileo grown to maturity discoursing with the Doge Leonardo Donato and some senators of Venice on the use of the telescope. In the background is a worried-looking man, Paolo Sarpi, an observer and experimenter who, like Galileo, ran afoul of the ecclesiastical authorities. A third fresco by Sabatelli, depicting the maestro as old and blind in the villa at Arcetri, tells the story of a frequent scene in his last weeks: conversation about mechanics with Torricelli sitting and Viviani standing near by.

A larger fresco, by Giuseppe Bezzuoli, in a lunette, celebrates Galileo's first deliberately controlled experiment, to prove the law $S = \frac{1}{2} At^2$. It exhibits, in short, the modern scientific technique. The performance was, if not the first fully explicit and articulate application of the method, at least one of the first in the modern world. In the foreground is the apparatus, an inclined plane. Behind it stands the master himself explaining the result of the experiment to his philosophical friend Iacopo Mazzoni. In front of the apparatus is a kneeling monk with a look of dazed concentration on his face, checking the speed of the rolling ball by his pulse. On the left, in a group of Scholastic professors, one is amused and another is at his wit's end, seeking to explain away the results of the experiment by a tome of Aristotle. On the right sits Giovanni de' Medici, a dabbler in mechanics. He seems suspicious. Galileo had previously earned his enmity by pointing out a defect in a contraption Don Giovanni had invented to dredge the harbor at Leghorn, and the nobleman is loath to have his critic win prestige by clinching the advantage in a public demonstration. Leaning over the Medici is the provost of the university, with a mildly quizzical expression on his aristocratic face. Aside from Mazzoni, the only sympathetic enthusiasts among the audience are some youths who restrain themselves with difficulty from helping in the experiment. The locale of the scene is made precise by the background of the Cathedral and the Leaning Tower of Pisa. In this picture are hints of the elements from which Galileo was destined to find opposition throughout his life: well-meaning piety, tradition-ridden scholarship, and the jealousy of powerful dilettantes.

Across the Arno from the Tribuna is the Museum of the History of Science, where most of Galileo's relics are preserved. This museum, the result of the First National Exposition of the Sciences at Florence in 1929, is on the Piazza dei Giudici, not far from the Uffizi Palace. It is housed in the Palazzo Castellani, a plain edifice reminding one of a flatiron apartment building. The museum's

Galileo presenting a telescope to the Doge and Senate of Venice. Fresco by Luigi Sabatelli at the Tribuna di Galileo, Museum of Physics and Natural History, Florence.

Galileo demonstrating experimentally the law of bodies falling under the force of gravity. Fresco by Giuseppe Bezzuoli at the Tribuna di Galileo, Museum of Physics and Natural History, Florence.

collection of sixteenth- and seventeenth-century devices to illustrate mechanical principles is a revelation. It shows the nature of the new method more convincingly and vividly than a textbook on inductive logic. The most imposing of the devices is a wooden runway to exhibit a body rolling downhill under the force of gravity. Fixed at intervals on the runway are bells, each of which the rolling body strikes and rings as it descends. A pendulum is attached to the high end as a timekeeper. The apparatus resembles that in Bezzuoli's fresco, but it is not a relic of Galileo—although the venerable museum guide is likely to introduce it as such to the uninformed.

Other exhibits are Galilean in type, such as a squat cardboard microscope, a pendulum clock patterned after the design dictated to Vincenzio by his blind father, and a sturdy wooden armchair. The only articles in the collection reasonably guaranteed to have come down to us from Galileo himself or from his period are a broken object lens, two telescopes, proportional compasses, a lodestone with armature, and a finger.

From the antiquarian point of view the object lens is the most interesting. The documentary evidence for its pedigree is almost complete. Before the lens came into the Museum of the History of Science it was in the Museum of Physics and Natural History, to which it was assigned in 1793. The ivory frame still holding it was carved in 1677 by an *intagliatore* named Vittorio Croster, who was paid 19½ lire for his efforts. Previously the glass was owned by Cardinal Leopoldo de' Medici, whose will (1675) lists it among his household effects. The cardinal had received it from the heirs of his brother Ferdinando II, Grand Duke of Tuscany, at the insistence of Viviani, Galileo's last disciple, probably because the churchman and Viviani were fellow-members of the Accademia del Cimento. Ferdinando was the son and successor of Cosimo II, the patron of Galileo. This lens, according to the records, was the one by which the first four of Jupiter's eleven moons were discovered —the four "Medicean Stars," as Galileo called them—and Cosimo requested the lens as a gift but died before the astronomer could part with it.

The other relic with an authentic pedigree is the finger. The American visitor may be somewhat astonished that an anatomical antique of this sort should be exhibited, but the Italians have a different feeling in the matter, as evidenced by the number of parts of the bodies of the great in religion they have kept on display through the ages. Galileo's finger is, according to the museum's catalogue, the index of his left hand, and was severed on March 12, 1737, when his remains were moved from his first resting place, near the Chapel of Saints Cosimo and Damiano, to the mausoleum where they lie at present. The museum's notes add that in the opinion of F. Leoncini, professor of legal medicine at the University of Florence, the finger is really the middle finger of Galileo's right hand. Two other fingers are said to be preserved in Florence in the reliquary of Dr. Luigi Rosselli del Turco.

Our next pilgrimage should be to the mausoleum in the medieval Franciscan church of Santa Croce, which faces a piazza once used for horseracing and football. For the celebrated dead buried or commemorated in this church one may compare it to Westminster Abbey, and for the quaint frescoes of Giotto adorning its walls one may think of it as an incomparable art gallery. Santa Croce does not give the impression of being as jammed with memorials as its English counterpart, and yet its dim, spacious interior holds hundreds of tombs, monuments, and tablets, on the walls, in the pillars, and on the floor. Here are buried honored Franciscan monks, noblemen, musicians, artists, poets, soldiers, humanitarians, and scientists. Here are the tombs of Machiavelli and Rossini, and memorials to Dante, to Leonardo da Vinci, and to Amerigo Vespucci. On the right of the entrance is the sarcophagus of Italy's supreme artist, the painter-sculptor-architect Michelangelo. But what will awaken the most sympathetic emotion in the bosom of the student of the history of science is the sarcophagus of Galileo on the left. The Italians show good judgment by placing at the head of this avenue of immortals on either side of the wide nave the tomb of Italy's greatest artistic genius and the tomb of her greatest scientific genius.

The head and foot of Galileo's tomb are guarded by baroque females, one representing astronomy and the other geometry. Above the sarcophagus is a relief of the four Medicean Stars in orbits encircling Jupiter. Above them in a niche is a bust of Galileo sculptured by Foggini or Ticciati. Galileo is represented with his head raised toward the sky and with a telescope in his right hand. Beneath the tomb is an inscription beginning:

Galilaevs Galileivs patric. Flor. geometriae astronomiae philosophiae maximvs restitvtor nvll aetatis svae comparandvs hic bene qviescat vix. a. LXXVIII. obit. a. MDCXXXXI. . . .
("Galileo Galilei, patrician of Florence, supreme restorer of geometry, astronomy, and philosophy, without compare in his age; may he rest well here; he lived for 78 years, died in 1641. . . .")

The raising of this mausoleum was the work of Viviani. He spent years of diplomatic effort to get his master's remains transferred to honored ground, but it was not until 1737, almost a century after Galileo's death and a generation after his own, that ecclesiastical disapproval softened to the point where reinterment became possible.

Near Santa Croce is the Central National Library of Florence in a handsome new edifice built under Mussolini. Those with a bent for bibliography will delight in looking through the catalogues to spot the library's holdings of Galileiana. The catalogues are in two sets of manuscript folio volumes, the earlier, designated *Fondo Palatino,* closing with 1860, and the latter, *Magliabechiana e Nazionale,* ending with 1886. Later accessions are listed in files of manuscript cards and cards on which printed clippings are pasted. One could spend hours examining the records of the works by and about Galileo: all his treatises in all their editions, his published letters, anthologies of his works, biographies, and analyses and critiques of his scientific method, of his scientific contributions item by item, of his literary opinions, of his philosophy, of his place in the history of civilization. There is even a work on the propagation of his ideas in China.

One will be struck by the number of anthologies. About three dozen entries for these are in the catalogues from 1868 to 1949. Since the anthologies are for use in the schools, they are an index to the value placed upon Galileo by Italian educators. A point seldom appreciated among students of the history of science is that Galileo is read today in Italian as much for the excellence of his literary style as for his significance as the father of experimental physics and telescopic astronomy.

One will be astonished at the number of Galileo's books written in Italian. He often used Latin, as was customary among the learned in his age, but most of his better known works—for example, the *Dialogo* and the *Dialoghi*—are in the language of the people. This suggests a valuable extrascientific achievement of Galileo: that he played the same role in Italian as Descartes did in French and Sir Francis Bacon in English and as, much later, Hu Shih has done in Chinese. He was one of those hardy souls who made the colloquial language, as

The aged and blind Galileo discoursing with his pupils Torricelli and Viviani at the villa in Arcetri. Fresco by Luigi Sabatelli at the Tribuna di Galileo, Museum of Physics and Natural History, Florence.

distinguished from the classical, a respectable instrument for conveying ideas. There is a possibility that the *Dialogo* would never have been banned if it had been written in Latin, for then no one would have understood it except the fraternity of safely indoctrinated scholars, whose morals it could not have corrupted.

The Central National Library is said to contain most of Galileo's manuscripts, which are at present under investigation by experts and which may be seen only by prior arrangement with the director.

From the library one may easily reach two other memorials, a statue and a portrait. The former is in the open air in an avenue of statues stretching along the front of the Uffizi Palace in two rows on either side of the Piazalli degli Uffizi, almost to the Arno. The statues represent celebrated Tuscans such as Amerigo Vespucci, Machiavelli, Dante, Michelangelo, Leonardo da Vinci, and Giotto. Galileo, with his back to the Arno, faces the row on his left, and stands opposite Amerigo Vespucci: the one gave his name to the continents of the New World, the other opened the way to knowledge of nature. The portrait, by a member of the Sustermans school, is at present in the Hall of Jove in the Pitti Gallery. It depicts the maestro as venerable, with a light shining on his face and with clear, searching eyes.

FRAGMENT OF AN INSCRIPTION (XX CENTURY)

on what far star's celestial wall
will fire-struck adamant recall
how we held funeral for you, tamers of horses?

R. S. Brumbaugh

Developing Forests Resistant to Insect Injury

S. A. GRAHAM

S. A. Graham was born on Maryland's Eastern Shore, near Salisbury, on March 22, 1891, and lived in seven different states during his boyhood. He received the Ph.D. in entomology from the University of Minnesota in 1921, but two years before that had investigated the spruce budworm outbreak in eastern Canada for the Canadian Entomological Branch. His forest insect studies have led him into nearly every state in the U. S. and into Canada's eastern provinces. He is the author of Principles of Forest Entomology *and (with O'Roke) of* On Your Own, *a book written for use in the "Survival" course offered at the University of Michigan during World War II. Dr. Graham is professor of economic zoology at Michigan.*

TO THE person who has even a passing acquaintance with the forest there appears to be an inseparable association between trees and insects. A picnic in the woods without a creeping caterpillar, a grasshopper, or an ant would indeed be an unusual experience. Outbreaks of borers, defoliators, and aphids have arrested the attention of almost everyone who has had any out-of-doors experience. And so insects and trees are inextricably associated in our minds. The idea that some forests may be practically immune to insect injury is foreign to most people, however; as a matter of fact, it will be equally strange to many forest managers and even to some forest entomologists, who think of insect control in terms of direct action.

For years, however, evidence has been accumulating that insect outbreaks in the forest are not matters of chance. They are made possible by combinations of favorable climatic, edaphic, and biotic effects. When environmental conditions become favorable an outbreak is certain to develop; on the other hand, if conditions are not favorable, safety from insect-caused injury is equally certain. Since many of the factors determining insect abundance may be controlled by man, we have at our command a powerful means of preventing outbreaks. By wise use of the axe and saw in thinning, pruning, and harvesting, or by proper planting, draining, or scarifying the forest floor, conditions that will make outbreaks impossible can frequently if not always be created.

How to develop forests resistant to insect injury has long claimed the attention of the writer, but when the preparation of this article was undertaken the task of presenting the subject clearly and succinctly seemed much more difficult than when the title was first selected. One thing was clear. The control of any noxious insect, in the final analysis, is a problem of regulating a population of living organisms. If an insect pest is to be controlled, its characteristic powers of reproduction must, on the average, be equaled by the forces that cause mortality. If damage to the forest is to be avoided, this equilibrium between the forces of production and the forces of destruction must be attained at a relatively low population level, so that there will not be enough insects present to cause serious injury to the trees on which they feed. Thus reproductive potential, environmental resistance, and the relation of these forces to the insect's abundance might appropriately serve as our central theme.

Preventive control is invariably accomplished by manipulating, in one way or another, one or more factors of environmental resistance; but the discussion of the interplay of the forces of production and resistance is by no means simple, and cannot easily be confined within the limits of a brief paper.

All things considered, it seems best to avoid theoretical discussion and to describe briefly the results of a number of studies that have led us to become enthusiastic about the possibilities of creating and maintaining insect-proof forests.

Even the advent of DDT and the perfection of inexpensive techniques for applying it from the air do not alter the fact that preventive practices are cheaper and in the long run more effective than direct control by chemicals. Unfortunately, the spectacular success of forest spraying operations during recent years has tended to lull us into a false sense of optimism, with the result that many expect too

much from chemical control. The truth is that chemicals alone cannot solve our forest insect problems.

In our enthusiasm about the effectiveness of chemicals we are likely to forget one important consideration. Although the current crop of insects can be poisoned, the forest conditions favoring outbreaks cannot be changed to man's advantage by spraying. As a matter of fact, after the immediate effects are dissipated, spraying may have the opposite effect and produce conditions especially conducive to the increase of pests, by destroying along with them beneficial parasitic and predatory insects.

No forest can be sprayed so efficiently that all the individuals of a species will be killed. Neither can it be sprayed so as to kill only the pest against which the treatment is directed. Some pests will survive to reproduce another army of forest enemies, and some desirable organisms—parasites, predatory insects, and other forms favorable to man's best interests—will certainly suffer injury. Following treatment with DDT, sporadic outbreaks of spider mites, aphids, and other sucking pests have been frequent, thus sounding a warning that not all the effects of spraying are desirable. These bad effects are transient where small areas are treated, because both desirable species and pests will rapidly invade from adjacent areas. The speed of recovery will be directly proportional to the number of survivors and the size of the area treated. Both the good and bad effects of chemical treatment are ordinarily temporary. Within a year or two the forest community will have returned to its previous state, and the stage will once more be set for an upward surge of the pest populations. For these reasons we must expect an early return of outbreak conditions following spraying. Repeated chemical treatments will therefore be required as long as the forest remains in a susceptible condition. Because of the unavoidable disruptive effects of chemical treatments, we may be certain that the more we spray the more we shall be compelled to spray. Chemical treatment is an emergency measure that should only be used when preventive practices fail. This being true, the encouragement of forest practices designed to prevent insect outbreaks is just as important as before the development of DDT.

The idea that forests relatively resistant to insect damage could be developed had its birth years ago. At first it was scarcely recognized as having any general significance, but as project after project through the years has pointed in the same direction, there has gradually developed the conviction that protecting forests against insect injury by making them undesirable places for insects to live has almost unlimited possibilities.

In recent years it has become apparent that silvicultural practices designed to control one insect pest will very frequently serve to check others as well. We now realize that certain forest types, the mixed hardwood–hemlock types of the Upper Peninsula of Michigan, for instance, the mixed pine–hardwood–spruce types, the mixed forests of the Douglas fir region, the mixed coniferous forests of the western slopes of the Rocky Mountains, and many others, are almost never severely injured by insect outbreaks. On the other hand, pure pine stands, pure hemlock stands, forests that are predominantly balsam fir, aspen, or birch are frequently subjected to insect outbreaks and as a result are severely damaged or sometimes killed outright. A realization of these facts has led to the special study of some insect-resistant forest types, the objective being to determine as accurately as possible how these types originated naturally, what silvicultural practices can be used to preserve them, and what practices may be used to convert susceptible types to a resistant condition.

The experimental testing of silvicultural practices designed to produce a desired forest mixture is a long-time process, but fortunately it is not often necessary to await the completion of experiments to find an answer to silvicultural problems. The forest as it develops preserves its own history, and by studying existing stands nature's silvicultural practices may be disclosed. Experiments may eventually point to improvement over nature's plan, but for the present we shall do well to follow her example. By careful analysis of present conditions, by the measurement of tree rings, by the examination of forest debris such as stumps and fallen trees, and by the study of soil characteristics and the superimposed layers of decayed and partially decayed vegetation, it has been possible to reconstruct forests as they were 50, 100, 300, and sometimes as much as 500 years ago. These unwritten records are so clear in some instances that we feel as if we had watched developments through the centuries. In other instances the evidence has been destroyed by fire, wind, or the destructive activities of man, so that we can only see back a decade or two. But enough evidence can almost always be found in a given locality to give a clear picture of how the original forest developed.

The idea that insect outbreaks can for the most part be prevented by creating forests with certain characteristics originated almost simultaneously in the minds of a number of forest entomologists, each of whom has contributed to the thinking of the

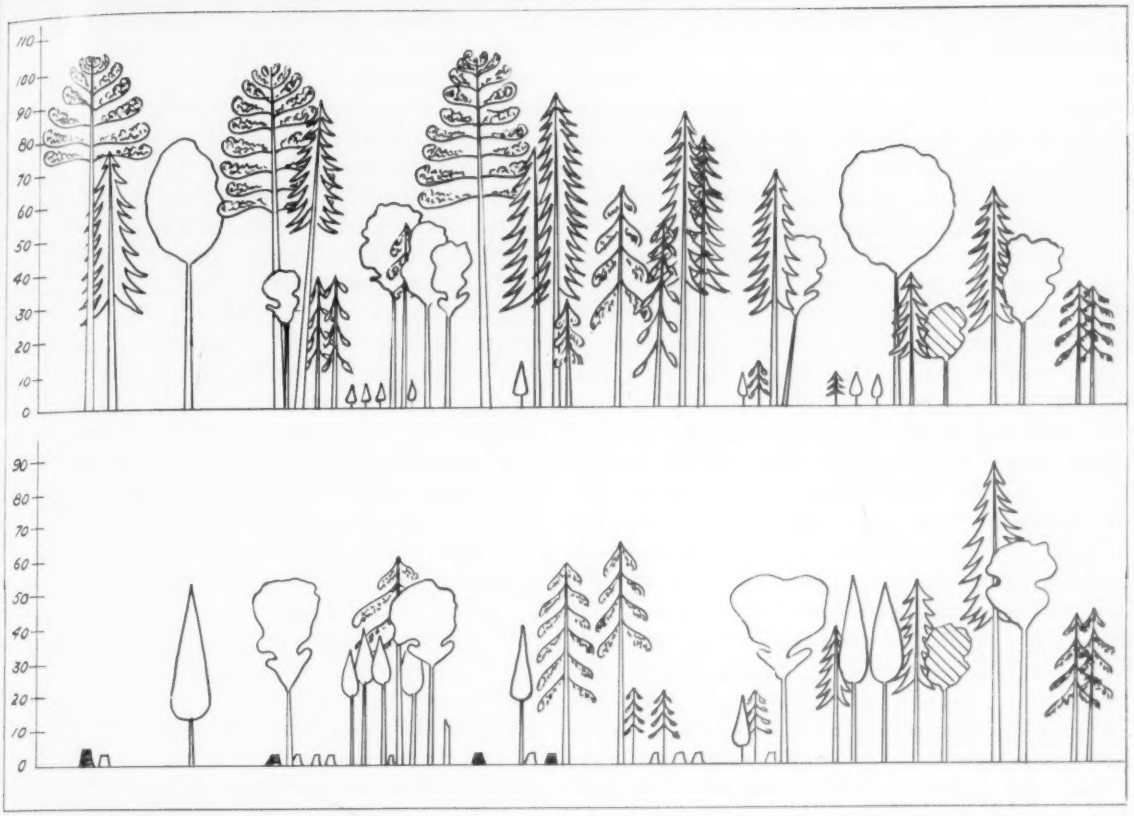

Diagram representing actual conditions on 1/20 acre of a mixed forest highly resistant to insect injury. Upper diagram represents conditions in 1890 before the white pine was cut. The lower diagram depicts conditions in 1942 after a selective cutting in 1941. Shaded stumps are from trees cut in 1895, unshaded stumps from trees removed in 1941. Following the latter operation, many seedlings of balsam fir, white spruce, and maple have become established, thus promising to maintain a desirable mixture for later timber crops.

others. The first suggestion that the character of a forest has an effect upon its susceptibility to insect injury came to this writer from an investigation of the white pine weevil, made during the second decade of the century. That study was a maiden attempt at research, patterned along lines already laid down by others. Research was properly guided into the customary channels by a preliminary examination of literature. Taxonomic characteristics of the insect and its close relatives were looked into, the habits and life history were investigated, and finally measures were tested for controlling the insect.

In those days spraying was almost synonymous with insect control. Good insecticides had been found, and effective machinery for their application to crops had been devised. "Our insect foes are increasing; we must spray!" was a statement repeatedly heard from the rostrum in economic entomology courses. So, naturally, sprays had to be tested against the weevil. Another recommendation then current for the control of borers and bark beetles was to "cut and burn the infested trees." If enough of the infested material could be destroyed, it was reasoned, there would not be enough insects to cause damage to whatever trees were left. Unfortunately the procedure almost never worked in practice, and it certainly failed to satisfy the unlucky timber owner who was advised to cut and burn the infested trees on his "back forty" in order to protect his neighbor's trees. If neither spraying nor cutting and burning worked, it was customary to conclude a report on any forest insect with the statement "Unfortunately, under present economic conditions, this pest cannot be controlled." The inference was that the control of forest pests would have to wait until the value of wood reached a point that would justify application of the relatively expensive control measures then current. The beginner thus was not only provided with a pattern for his experiments, but at the same time he was given an excuse for failure. It is not surprising that insect outbreaks in the forest came to be regarded as acts of God, like the weather. Even now this defeatist attitude is still maintained by some who should know better.

The pattern set by others was followed in the study of white pine weevil control. Infested shoots were collected and destroyed, and every available kind of insecticide was tested. But even before the results of these experiments were apparent, it was evident that the costs involved were unreasonably high and that direct control by the methods tested would have a limited application.

Until then all efforts to study the weevil had been directed to locations where it was especially abundant. But with recognition of the impracticability of direct control, other areas were examined in search of new ideas, at first rather hopelessly and then with increasing interest. In some places the pines were much more severely injured than in others. Sometimes groups of trees showed no sign of injury, even though other stands in the immediate vicinity were practically ruined. What were the reasons for the differences? These observations opened up an entirely new approach to the problem of weevil control. Sample plots were laid out in as many different situations as possible, and conditions were examined in detail. To shorten the story of research that extended over a number of years and included numerous localities in the range of the Eastern white pine, we learned that white pine grown from infancy in dense stands invariably produced a crop of good trees, but that open or scattered stands were always severely injured or made completely worthless by weevil attack. Furthermore, pines growing with hardwood trees, such as birches, aspens, maples, and elms, for example, were practically never attacked by the weevil. Thus a practical way of preventing damage by the white pine weevil was discovered, and the silvicultural practices by which it could be accomplished became obvious.

After completion of the weevil study, the spruce budworm came into the limelight. During a period of ten years that insect established its reputation as "Insect Enemy No. 1," by destroying enough timber to operate then existing pulp mills for forty years. If all of the killed trees could have been cut into four-foot lengths and stacked in cord-size piles end to end along the equator, the string of cords would have encircled the earth ten times.

We had the opportunity of studying the budworm outbreak, or rather series of outbreaks, both in Canada and in the Lake states. Remembering the results of the weevil experiments, we looked for differences in the degree of infestation, and when they were found attempts were made to compare conditions on the heavily infested areas with lightly injured stands in the same localities. Gradually evidence piled up to show that large quantities of mature balsam fir were always associated with severe injury by the budworm, and that spruce-fir forests containing in the upper crown canopy less than 50 per cent balsam were seldom killed.

Study by Tothill and other forest entomologists, including the writer, revealed the reason for this difference. Contrary to previous reports, the young larvae, instead of feeding in late summer when they hatch from the eggs, immediately seek hibernating quarters, where they pass the winter without eating. They emerge the following spring, hungry from their long fast, and unless they then find suitable food, many of them perish. At first they often mine the needles, but soon they require the soft, fresh tissues of expanding shoots or buds. When such food is unavailable, the larvae will continue to mine both needles and unopened buds, but such food is not conducive to most rapid increase.

It happens that the balsam fir buds respond to the spring weather in such a way that the new shoots are in an ideal stage to provide food shortly after the hungry worms emerge from hibernation. Spruce, in contrast, starts growth two or even three weeks later than balsam fir. Thus, in a forest that contains large quantities of balsam fir, the budworms survive the difficult spring season in larger numbers than in other types. Further observations revealed that the adult moths lay their eggs almost exclusively on large trees, whose crowns are in a dominant position. Trees sheltered by other trees are never infested except by the surplus caterpillars dropping from the larger trees. Even balsam fir is safe from attack until it attains a dominant position in the forest canopy. Still another factor appears to influence the severity of budworm outbreaks. On small areas outbreaks seem less likely to occur than on extensive areas, and when they do occur, they are usually sporadic and less injurious.

In this way the study of an insect's ecology led to an understanding of the means by which it can be controlled. The exact silvicultural techniques that can be used to develop forest types resistant to the spruce budworm still remain to be worked out in detail, but the kind of forest to be desired is perfectly clear. Furthermore, there is no doubt that the proper regulation of cutting practices in fir-spruce types can accomplish control.

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A careful study was made of the various observable factors that caused insect mortality. Population counts were made day by day on sample trees to determine the rate of mortality and the causes of death. It was determined that resin was one of the chief causes. The small larvae, feeding on the expanding young shoots of the pine, were frequently overwhelmed by the flow of this sticky material from the wounded tissues. The g this cause often resulted in a ma in the insect's numbers.

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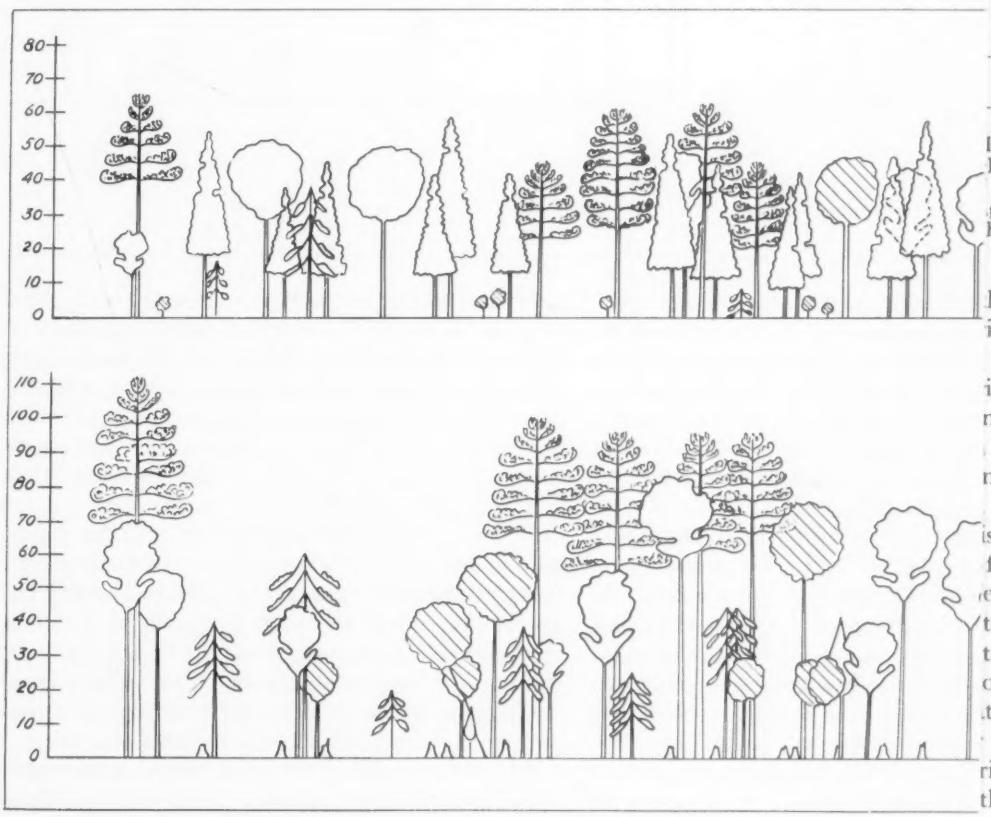

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The pattern set by others was followed in the study of white pine weevil control. Infested shoots were collected and destroyed, and every available kind of insecticide was tested. But even before the results of these experiments were apparent, it was evident that the costs involved were unreasonably high and that direct control by the methods tested would have a limited application.

Until then all efforts to study the weevil had been directed to locations where it was especially abundant. But with recognition of the impracticability of direct control, other areas were examined in search of new ideas, at first rather hopelessly and then with increasing interest. In some places the pines were much more severely injured than in others. Sometimes groups of trees showed no sign of injury, even though other stands in the immediate vicinity were practically ruined. What were the reasons for the differences? These observations opened up an entirely new approach to the problem of weevil control. Sample plots were laid out in as many different situations as possible, and conditions were examined in detail. To shorten the story of research that extended over a number of years and included numerous localities in the range of the Eastern white pine, we learned that white pine grown from infancy in dense stands invariably produced a crop of good trees, but that open or scattered stands were always severely injured or made completely worthless by weevil attack. Furthermore, pines growing with hardwood trees, such as birches, aspens, maples, and elms, for example, were practically never attacked by the weevil. Thus a practical way of preventing damage by the white pine weevil was discovered, and the silvicultural practices by which it could be accomplished became obvious.

After completion of the weevil study, the spruce budworm came into the limelight. During a period of ten years that insect established its reputation as "Insect Enemy No. 1," by destroying enough timber to operate then existing pulp mills for forty years. If all of the killed trees could have been cut into four-foot lengths and stacked in cord-size piles end to end along the equator, the string of cords would have encircled the earth ten times.

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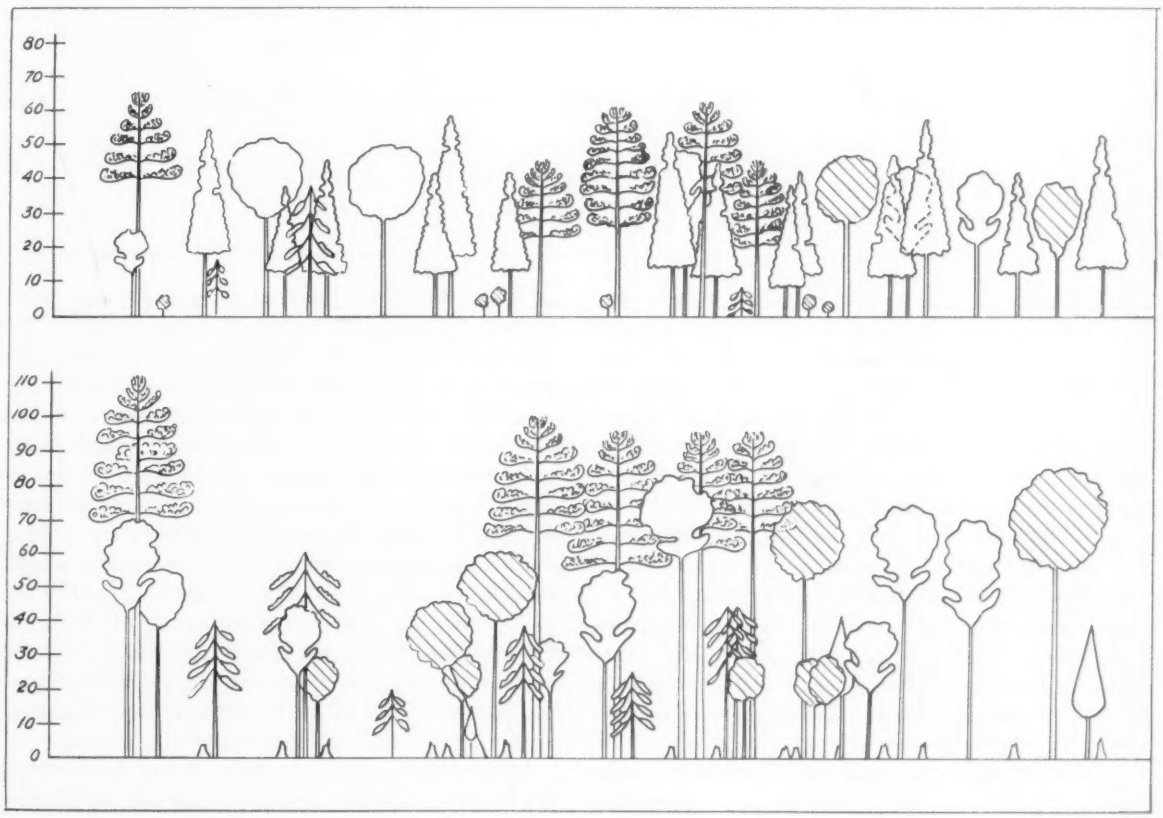
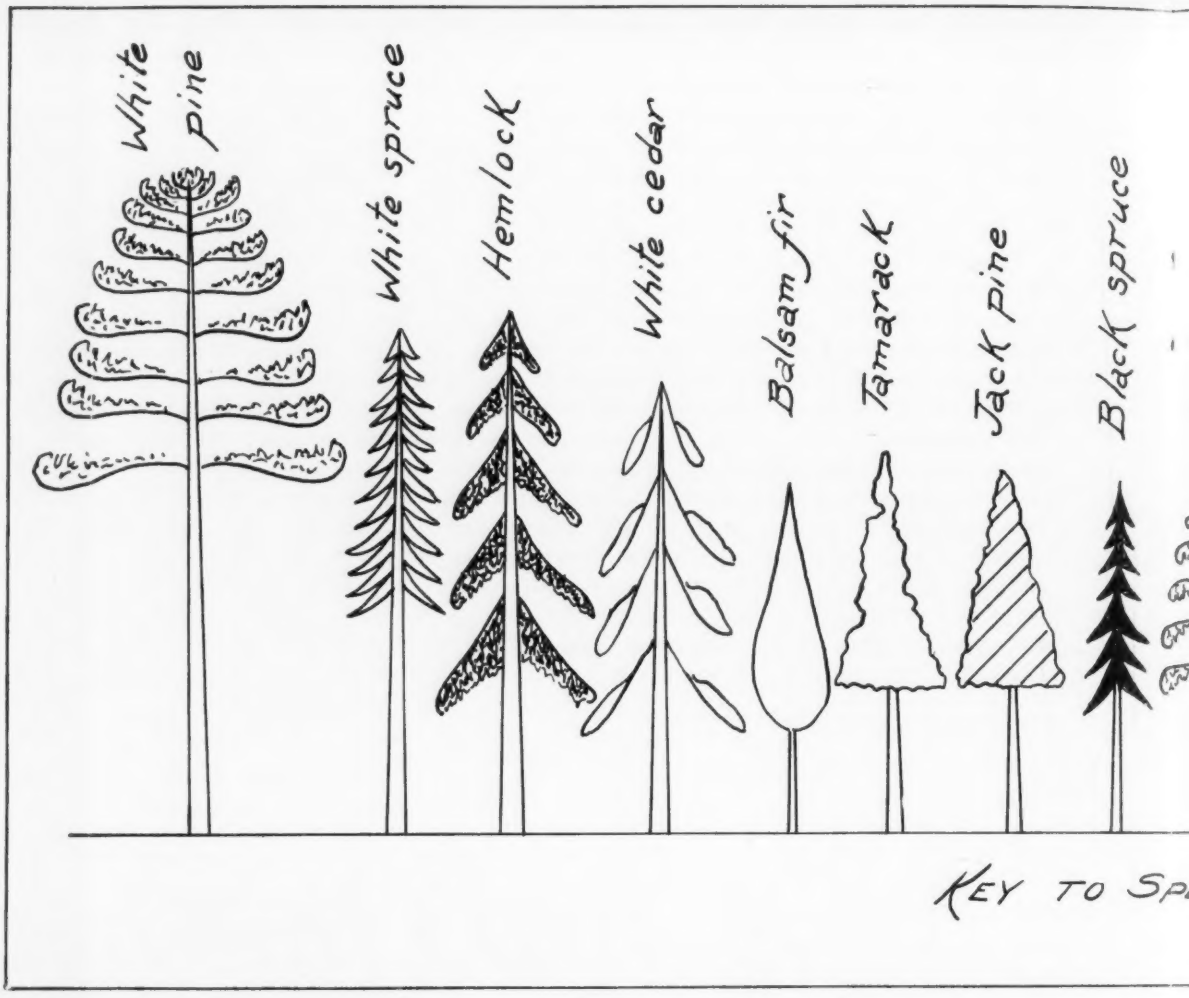
Further investigation showed that the caterpillers exhibited a distinct preference for staminate flowers as a source of early spring food. When available, these staminate flowers provided a relatively nonresinous location in which the tiny larvae could live and feed in safety. Furthermore, the larvae feeding on the staminate flowers grew more rapidly than those that fed on other tissues.

These observations led to the suspicion that the presence or absence of large quantities of pollen-producing flowers might easily be the factor that determined whether outbreaks might occur. Investigation led to the conclusion that outbreaks of the pine budworm only occur when the proportion of twigs bearing staminate flowers is in excess of 20 per cent of the twigs on the trees. Therefore, if trees were producers of an abundance of pollen they were more subject to injury by the budworm than if they were not pollen producers.

The production of flowers on a tree depends



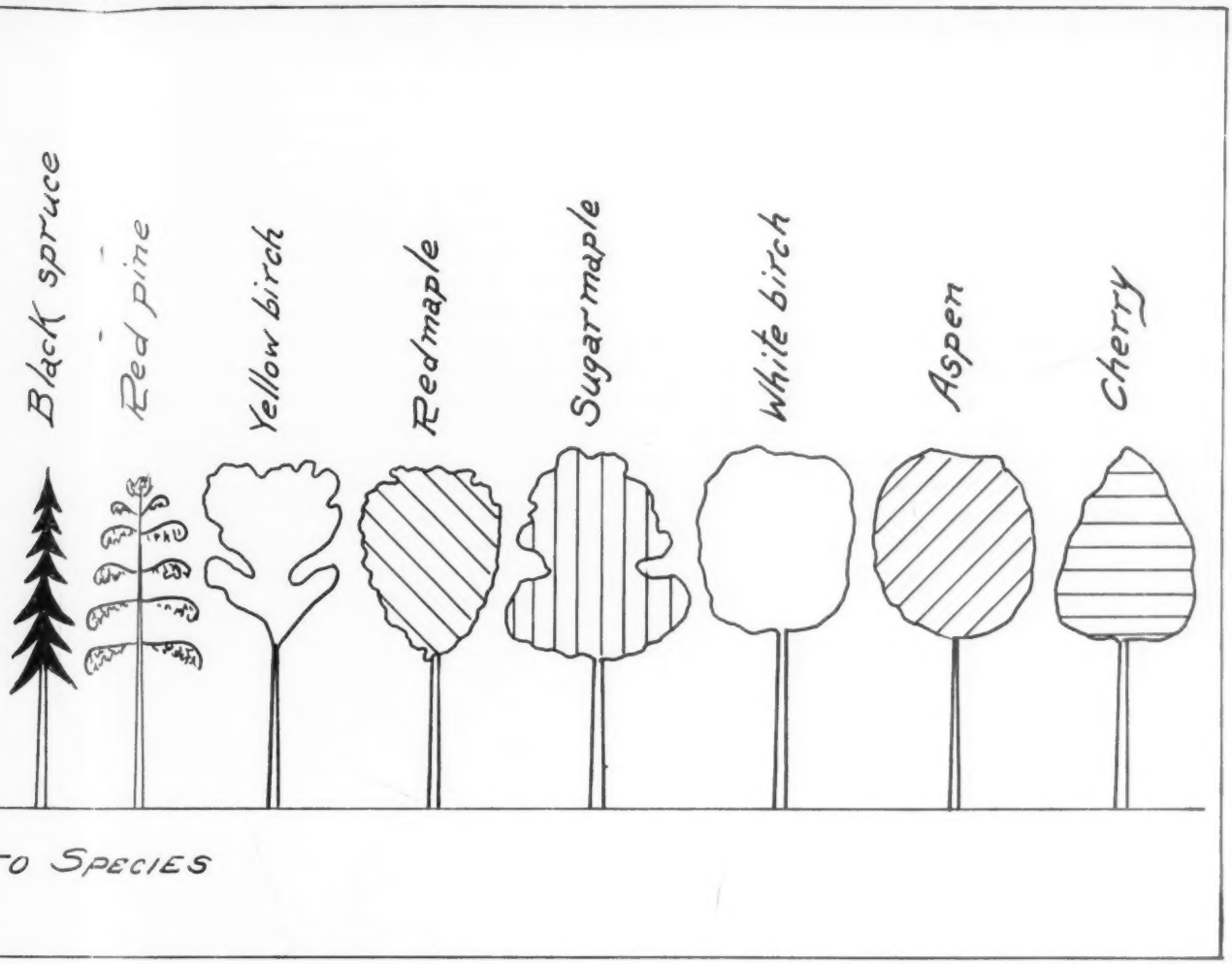
At times an insect outbreak may result in a safer forest. Upper diagram represents conditions in 1890, the lower 1942, after the tamarack had been killed by the larch sawfly. As a result of the sawfly outbreak the forest developed into a mixed type relatively safe from insect injury.



chiefly upon the root-to-crown ratio. Trees with large crowns in proportion to their root systems are usually great pollen producers, whereas trees with proportionately small crowns seldom produce any appreciable number of flowers. In other words, if the ratio of leaf surface to root surface is such that the amount of available carbon absorbed from the air as carbon dioxide is great in comparison with the available minerals absorbed by the roots, a tree will usually flower freely, and vice versa. Here, probably, lay the key to pine budworm control. By maintaining jack pine stands in a fully stocked, but still thrifty, condition, the carbon-mineral ratio could be kept sufficiently low to restrict the production of staminate flowers. Budworm outbreaks should be impossible under such conditions.

Soon after this hypothesis was developed on the basis of studies in natural stands, an opportunity to test it under practical conditions was presented. In the course of a timber stand improvement operation on the Huron National Forest, overtopping oaks were being removed to release a young stand of pine. This operation left a stand of poles and saplings with scattered, large-crowned, pollen-producing jack pines. When about a square mile had been treated in this manner, a budworm outbreak developed. The release procedure was then modified to include the cutting of the scattered large-crowned jack pine in addition to the oaks, leaving only thrifty poles and saplings. Where the pollen-producing trees were cut, the outbreak promptly subsided. On the area first treated and on the adjacent untreated forest the budworm outbreak continued to increase in severity. This experimental cutting demonstrated clearly that outbreaks of the budworm are to a considerable degree dependent upon an abundance of staminate flowers.

Still another insect common in the Lake states, the hemlock looper, appears to be susceptible to silvicultural control. This species has from time to time destroyed millions of board feet of timber. Although it has not been studied as intensively as



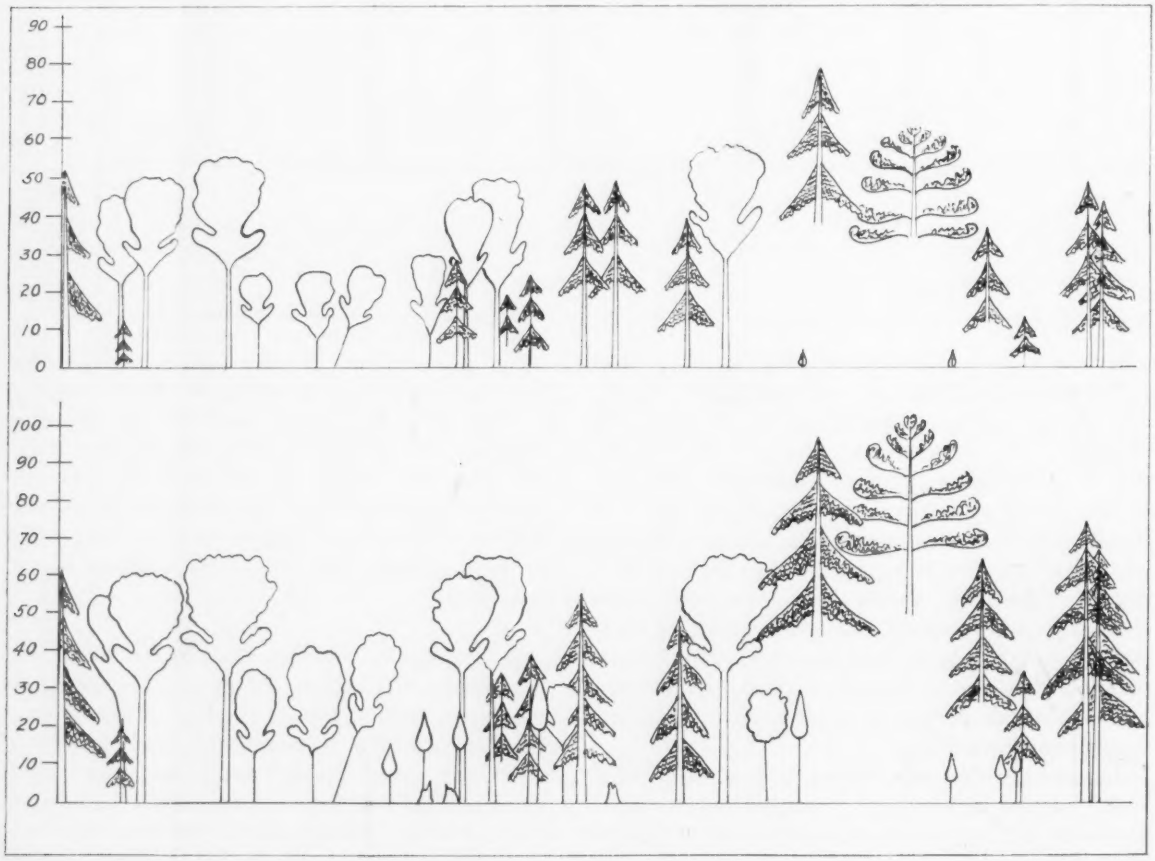
some other species, nevertheless one series of plots in Michigan indicates that although some defoliation occurs, little permanent damage is caused by the looper in forests where hemlock comprises less than 50 per cent of the dominant trees. These observations are in harmony with those of others in the Pacific Northwest, where the same insect or a very close relative is especially injurious to pure stands of hemlock. From these observations, the conclusion seems logical that pure stands of hemlock should not be encouraged and that mature hemlock should be promptly utilized. Fortunately, hemlock stands are usually replaced by other, safer types following cutting.

In several other cases general observation indicates that the outbreaks of insects are often associated with pure or nearly pure stands of single tree species. For example, the forest tent caterpillar outbreaks of recent years in the Lake states and in Canada have been restricted to pure stands of aspen. Some previous outbreaks of the same insect have occurred in pure stands of oak or of sugar maple. The pine tussock moth, on jack pine, the birch skeletonizer, the aspen leaf roller, and the striped maple worm are all common forest insects that are associated with pure stands. These facts lead to the unavoidable conclusion that mixed stands of trees are less likely to be attacked and injured by insects than are pure stands and, therefore, should be encouraged.

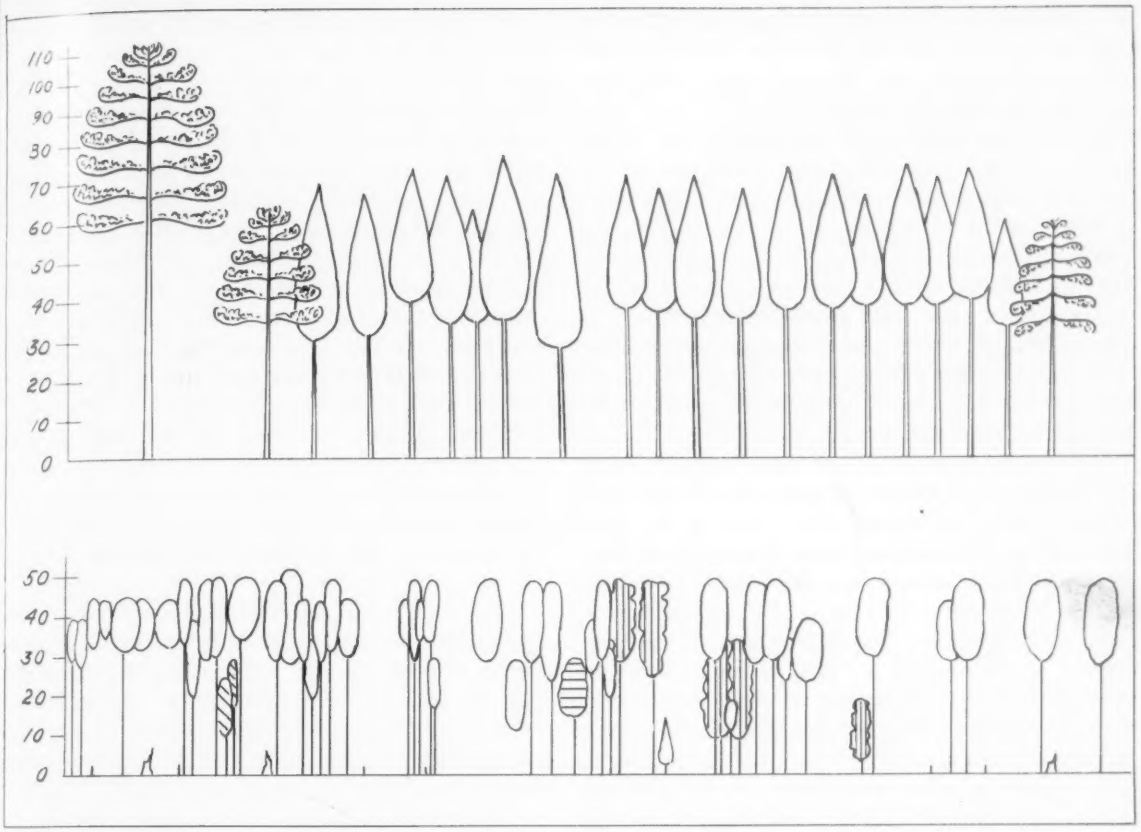
But we cannot yet control all insects by silvicultural methods. In spite of long and careful study, some insects still challenge the best efforts of forest entomologists. For instance, the larch sawfly, an insect that several decades ago killed more than 60 per cent of all the tamarack trees in the Lake states, is one of these. Tamarack is a tree that almost always grows in pure stands in swamps, not because it prefers swamps, but rather because it can become established on floating bogs where most other trees cannot grow. Given an opportunity

without competition on high ground, tamarack grows more rapidly than any other Northern conifer, but as a competitor it is a most unsuccessful species. It is therefore relegated to the swamps, where it is practically free from competition with other trees. By the time a stand of tamarack becomes mature, other more tolerant species have become established with it, leaving no room for tamarack reproduction. Only one generation of tamarack can usually grow on the same swamp area. As a result there is not much that the silviculturist can do to modify the conditions under which this tree grows naturally. As natural stands of tamarack approach maturity, outbreaks of the larch sawfly may logically be expected; then a race between the sawfly and the lumberman is likely to ensue. In a few special cases that permit regulation of the water level, the larvae in cocoons may be destroyed either by flooding or by draining, but, generally speaking, control of the larch sawfly by silviculture is not promising.

Similarly, the insects that attack other intolerant species like aspen and paper birch do not lend themselves so well to preventive measures of control as do those that attack the more tolerant species. Nevertheless, the axe and the saw, used at the proper time and in the proper manner, can do much to reduce losses. Observations indicate that mature or overmature forests of any species are more susceptible to injury by insects than are younger forests. It follows, then, that the forester should plan to utilize timber as soon as it is mature. By so doing, man will be able to substitute himself for nature's loggers, the insects. Furthermore, study of many outbreaks indicates that these phenomena occur most frequently and in most devastating degree where great areas, miles in extent, are largely occupied by the same susceptible type. If logging operations are planned and conducted in such a manner that cutting units are small, usually not more than forty acres, and adjacent areas are never cut in successive operations, a mixed-age forest will be



Natural succession leading toward predominance of shade-loving species may increase the danger of outbreaks. Upper diagram shows the forest as it was in 1890, the lower as it was in 1941. As the hemlock reaches a position of dominance, outbreaks of the hemlock looper are certain to occur. Trees unconnected with the base line are over, but not rooted on, the strip depicted.



An unsafe condition created by two successive forest fires. Upper diagram shows the forest as it was in 1875. This mixed forest of balsam fir and white pine became established following a fire about 1810. The balsam fir was killed about 1880, leaving the ground littered with a mass of dead and fallen trees. Between 1890 and 1895 a fire burned the debris, killing the pine and creating favorable conditions for invasion of aspen and white birch, a type often damaged by insect outbreaks. Lower diagram depicts conditions in 1942 after aspen had been removed by beaver and maple had begun to invade the area. Trees separated from the base line are not rooted on the strip depicted.

produced that will be far safer than the continuous even-aged forests of the same species that so frequently follow unregulated logging. By cutting on these small scattered units, forests that naturally grow in pure stands can be diversified by age classes and made relatively safe.

In the eastern United States most of our forests have been logged over. The mixed types of virgin forests that were resistant to the damage caused by insects have been replaced by temporary intolerant types in which frequent insect outbreaks of various kinds may be expected. One of the most pressing problems for the forest entomologist is to discover the most satisfactory means of converting susceptible types to a condition of greater safety. In the Pacific Northwest and California, where there are considerable bodies of uncut mature virgin timber, the entomologist is less concerned with temporary types. In the West many forests have passed their prime and have actually become decadent. As a result they are especially subject to the attack of various forest pests, and particularly bark beetles.

In the interest of economic stability, the period over which the virgin timber is removed should be extended as long as possible. If the cutting period can be sufficiently lengthened, so that the second-growth timber on the oldest cuttings will begin to produce valuable products before the virgin stands are entirely exhausted, the ideal objective would be attained. However, the possibility of accomplishing this desirable condition is probably gone for the present tree generation, thanks to the tremendously accelerated rate of utilization necessitated by war demands. But even before the war the danger of losses from insects was stimulating a more rapid cutting rate than was advisable. An operator might decide to hold a certain piece of timber in order to meet his requirements for raw material twenty years hence, but all too often bark beetles would attack the forest and destroy the reserved timber. Such experiences have discouraged long-time planning, and have encouraged lumbermen

to protect their investments in standing timber by rapid liquidation. In recent years, however, forest entomologists in the Western states have done much to slow this destructive process.

By devising methods of recognizing the virgin stands of ponderosa pine most likely to be attacked by bark beetles, they have encouraged operators to log the susceptible areas first, leaving the low-hazard stand until later. Also, by classifying the trees in a forest on the basis of age and foliage characteristics and then determining statistically the chance that trees in each class will be attacked by insects, they have shown operators how to create safer conditions by removing in partial cuttings trees belonging to the classes most likely to be attacked.

Still one more advance has been made by Western forest entomologists. Within any of the age-crown classes individual trees may be in poor health. If such sick trees can be distinguished, they can be utilized before they are attacked by bark beetles. Recognition of this has led to a system of risk rating based on the appearance of the tree crowns, the entomologist rating the trees according to immediate risk regardless of class. Removal of these trees in the course of logging operations makes for safe conditions even in overmature ponderosa pine. These developments have encouraged operators to enter into sustained yield programs that will aid materially in bridging the gap between the virgin and second-growth stands. The risk-rating system is used together with or independent of the age-crown classes to indicate current risk; in making sanitation cuttings in ponderosa pine, trees are removed on the basis of combined current health and class susceptibility.

Obviously we cannot expect to create in every forest conditions that will invariably protect trees from insect injury. Neither can we expect to accomplish overnight the desirable changes that can ultimately be made. We shall, therefore, be compelled for many years to resort to chemical control as an emergency measure. However, if plans are laid to adopt as far as possible silvicultural practices designed to produce the forest patterns that we know to be desirable, we may confidently expect to make future forests relatively safe from insect devastations. Our present aim should be: (1) To maintain the safe mixtures now existing; (2) to convert temporary hazardous types to safer mixtures by planting, scarifying the soil, improvement cuttings, and other practices; (3) to increase diversification in single-species forests by mixing age classes; and (4) to reduce hazard in mature stands by sanitation and improvement cuttings.

These are the objectives that every forest manager must have in mind if our forests are to be made more safe from insects. They are all objectives that can be attained with little or no expense above regular operating costs. In fact, most of the processes and procedures that will be used to create forests safe from insects are already a part of normal forest practices. The objectives can be attained easily if we plan a pattern, and work toward its construction. The possibilities of forest insect control by developing resistant types are so promising, and the hazards of excessive use of insecticides so real, that we shall do well to pay heed to nature's own methods of preventing forest insect outbreaks.

Agricultural Developments in Interior Alaska

E. WILLARD MILLER

Dr. Miller, who has been professor of geography and chief of the Division of Geography at The Pennsylvania State College since 1945, gathered the material for his article during field work in Alaska in 1948 and 1950. Last year he was the recipient of the Ray Hughes Whitbeck award in economic geography, which was given for the outstanding article in the field published in the Journal of Geography *during the preceding five years. Dr. Miller received his Ph.D. in geography at Ohio State in 1942.*

IN RECENT decades there have been many attempts to extend agricultural pursuits into subarctic areas. Agricultural development in Alaska is among the most important. Interest in farming in interior Alaska began with the discovery of gold in the Fairbanks area about fifty years ago, when large quantities of food were needed by the miners. It soon became common practice for Alaskans to have gardens, whenever possible, in order to produce part of their food and also to vary the monotonous pioneer diet. To obtain information about the agricultural possibilities of interior Alaska agricultural experiment stations were established at Fairbanks, Rampart, and Circle City before 1910. Since 1925 only the station at Fairbanks has been maintained. In 1935 the Mantanuska colony was established in south-central Alaska, and in the past 15 years much of the development and interest has centered on this region. There are several areas that have agricultural potentialities in the interior, but only the Fairbanks region of the Tanana Valley has a small agricultural settlement.

Environmental Factors

The physical environment, which is important in all agricultural regions, becomes paramount in the subarctic. Minute local changes in slope, soil, temperature, or permafrost conditions greatly affect agricultural conditions.

The farm belt of Fairbanks occupies two distinct physiographic areas—the bottom lands of the Tanana Valley and the terraces or benchlands of the foothills of the Tanana uplands (Fig. 1). The valley floor, cut by sloughs and old stream beds, is comparatively smooth and lies at an elevation between 520 and 600 feet. The benchlands begin at about 600 feet, and the highest points are a little over 1,400 feet. Those adjoining the valley floor vary from gentle slopes to sharp inclines, too steep to cultivate.

The differences in elevation make a considerable contrast in temperature conditions. The average length of the growing season on the higher slopes is 105 days for frost-tender plants such as potatoes, and 123 days for hardy plants such as pasture grasses. In the valley bottom the length of the average growing season is 10–15 days shorter, largely because of air drainage. There is, however, a great variation in the length of the season, which ranges from 24 to 137 days. The average temperature of the three warmest months is about 57°; the mean maximum is 68°, and the mean minimum 46°. The first part of June and the last of August are critical periods, for minimum temperatures lie close to 32°, and frost is likely to occur, with resultant crop damage.[1]

Precipitation appears to be essentially uniform throughout the region. The mean annual precipitation is about 10–12 inches, with about 60 per cent falling from May through September. August is normally the wettest month. For most crops, however, there is a deficiency of water, and irrigation is used on most vegetable gardens. An occasional dry spell in late spring will retard plant growth to such an extent that frost damage is likely in the fall.

In the Fairbanks district, as throughout Alaska, the type of natural vegetation is an excellent key to soil and drainage conditions (Fig. 2). On the benchlands, the Alaskan interior forest, typified by tall white spruce, balsam poplar, and white birch, is well developed. The ground cover consists of dwarf heath shrubs, mountain cranberry, a few mosses, dwarf dogwood, horsetail, and bluegrass. This vegetational cover develops on the well-

drained and relatively warm Fairbanks soil series,[2] which consists of wind-laid deposits of silty, very fine sand and forms valley slopes of about 2–15 per cent gradient. It is relatively good agricultural soil, brown in color, with an A horizon 6–10 inches deep and a yellowish-brown subsoil 3–8 feet in thickness. H. H. Bennett has compared it to the brown in color, with an A horizon 6–10 inches spread in the U. S. corn belt. Depth to permafrost varies greatly, sometimes being less than 2 feet but commonly more than 5 feet. One of the most serious problems in utilizing this soil is its tendency to erode easily when the land is cleared of its natural vegetation.

In the Tanana lowlands vegetation is typified by black spruce and brush, including dwarf willow, dwarf birch, Labrador-tea, blueberry, mountain cranberry, crowberry, and other small shrubs. This vegetation develops on the cold, poorly drained Tanana soil series, which is largely azonal, developing from water-sorted sediments that are derived from sandy micaceous material. The poor drainage is due to permafrost, which is usually 12–36 inches below the surface under the native vegetational covering. Thus, the C horizon may be completely frozen in places. When the land is cleared this soil develops into a very fine sandy loam, which is light gray-brown to dark yellowish-brown in color. In most cultivated fields the permafrost is more than 4 feet below the surface, and many areas that were once very wet are now deficient in water.

Land Ownership

There are three ways to secure a farmstead in Alaska—by direct purchase from someone who has title to land, by compliance with requirements for homesteading, or by direct purchase from the government of a small plot for vegetable gardening.

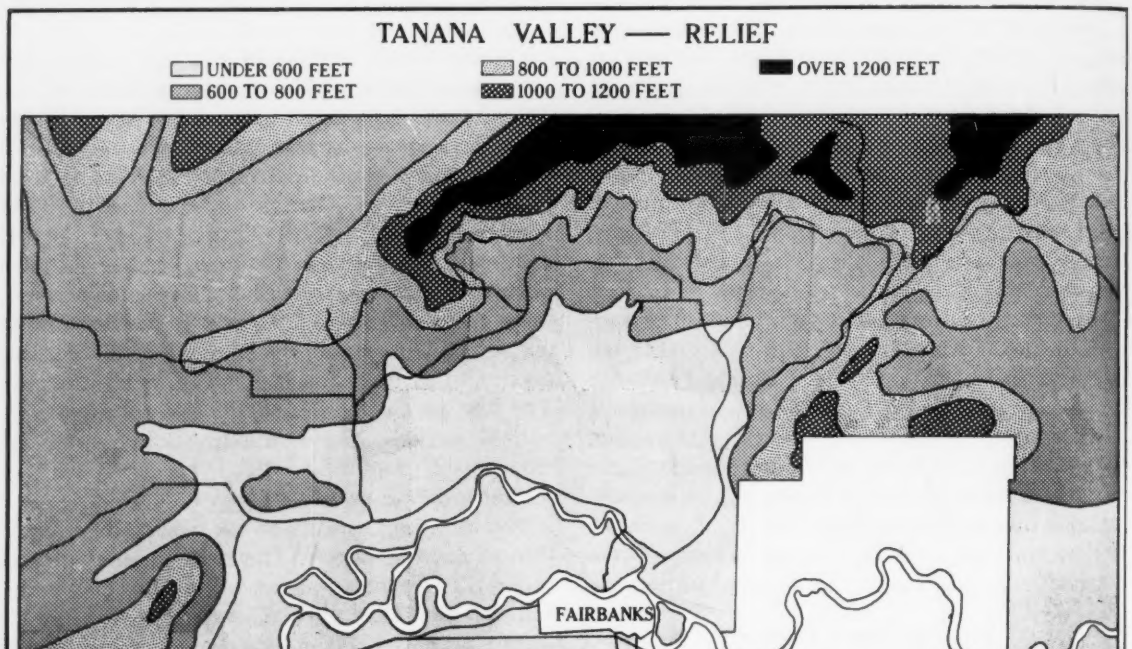


Fig. 1. Relief map of the Fairbanks region.

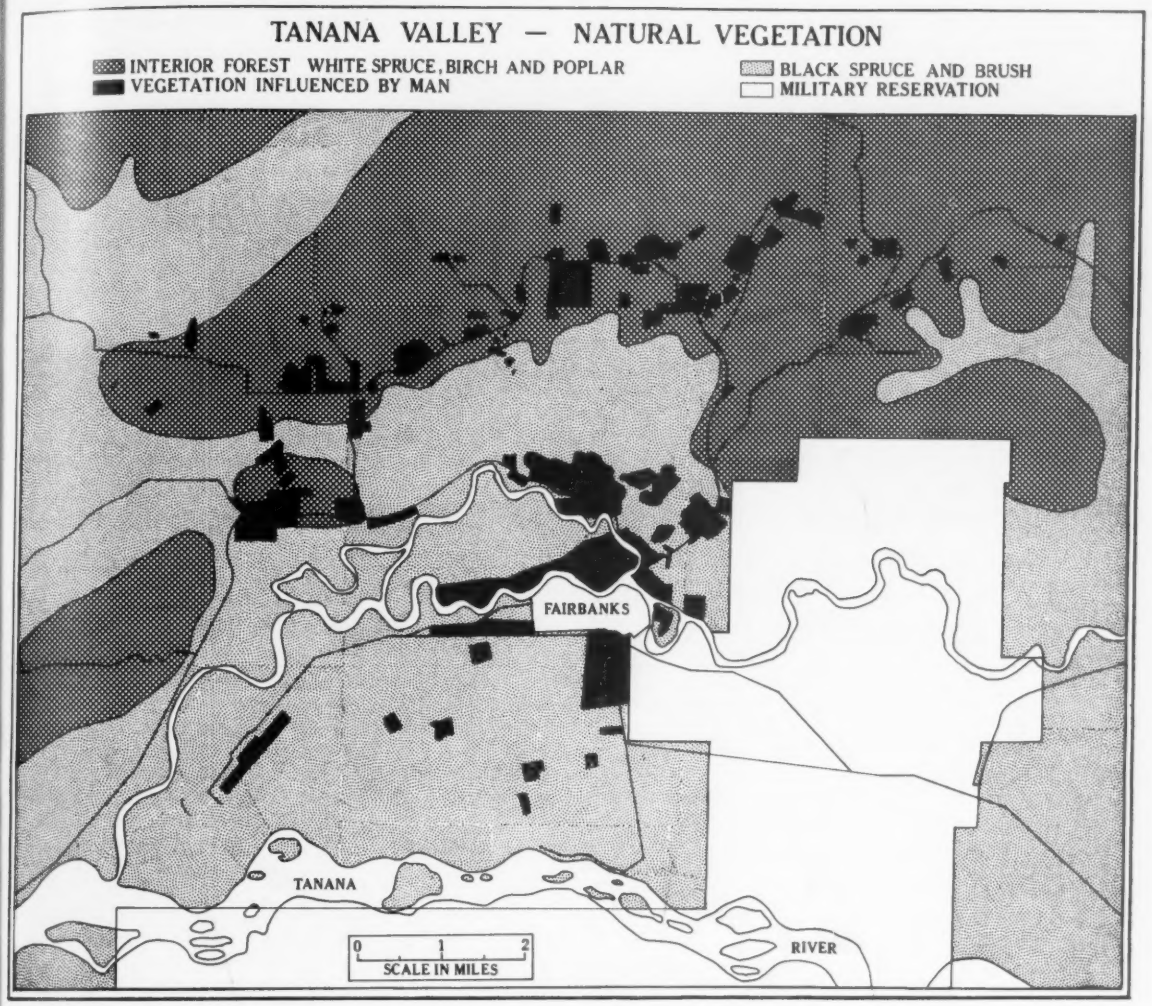


FIG. 2. Map showing natural vegetation of the Fairbanks region.

All unappropriated and unreserved land adaptable to agricultural use is available for homestead settlement.[3] The selection of a poor farm site has been the cause of a number of agricultural failures in the region.

Although farming is at present the main source of livelihood for only 30 or 40 families in the Fairbanks region, about 60 per cent of the land is privately owned or has been filed upon by homesteaders (Fig. 3). Farms average about 160 acres, but they may vary from a few to 320 acres. Slightly less than 20 per cent of the average holding is cleared, and about one third of the cleared land is normally idle or fallow each year.

There is considerable instability of farm population in this region. About 30 per cent of the land has been filed upon by present homesteaders. It is probable that a considerable number of them will not succeed in fulfilling the homestead requirements and will lose their land. In the Fairbanks district approximately 90 per cent of the privately owned land has been relinquished by one homesteader and acquired by someone else, or has been purchased after a patent has been secured by another owner.[4] In 1950 about 75 per cent of the farmers had owned their farms for less than six years. In recent years there has been much land speculation.

Clearing the Land

Since all land in the Fairbanks area is covered by brush, trees, or muck, or all three, the initial preparation of the land for cultivation has always been an expensive and difficult problem for the new settler. Until 1920 the usual procedure was to burn the area to be cleared and then to remove the remaining stumps by hand or by use of horses. This method had serious handicaps, for it was rela-

tively costly, and fire in the low, matted vegetation was difficult to control. By 1920, however, more than 900 acres had been cleared.

With the introduction of the tractor about 1918 the method has gradually been modified. The first step now is for the bulldozer to push the vegetation into windrows in the field. This exposes the ground and allows it to dry, thus lowering the permafrost level. After the material dries, the piles are burned. Since the soil is generally deficient in humus, it is common practice initially to plant rye or grass that will be plowed under the first year or two to improve the quality.

By the end of 1950 about 2,400 acres had been cleared, and much of this land is under cultivation. In recent years less than 100 acres have been cleared annually for farming purposes. It costs between $40.00 and $125.00 to clear an acre of land, depending on the nature of the vegetation and its general location. The lack of access roads to many good potential farming sites has retarded the clearing of land in some sections. In the farm belt about 70 per cent of the cleared land lies on the higher terraces and benchlands where vegetable and grain production predominates. The cleared land in the lowlands is used mainly for the production of pasture grasses and silage crops.

Crops of the Region

Vegetables were the earliest plants cultivated in interior Alaska and remain today its most important crop. They are not only produced commercially but are grown on a large number of garden plots, but the demand for vegetables has never been met by local growers. Latest tabulations show that the annual value of food imported into the Fairbanks

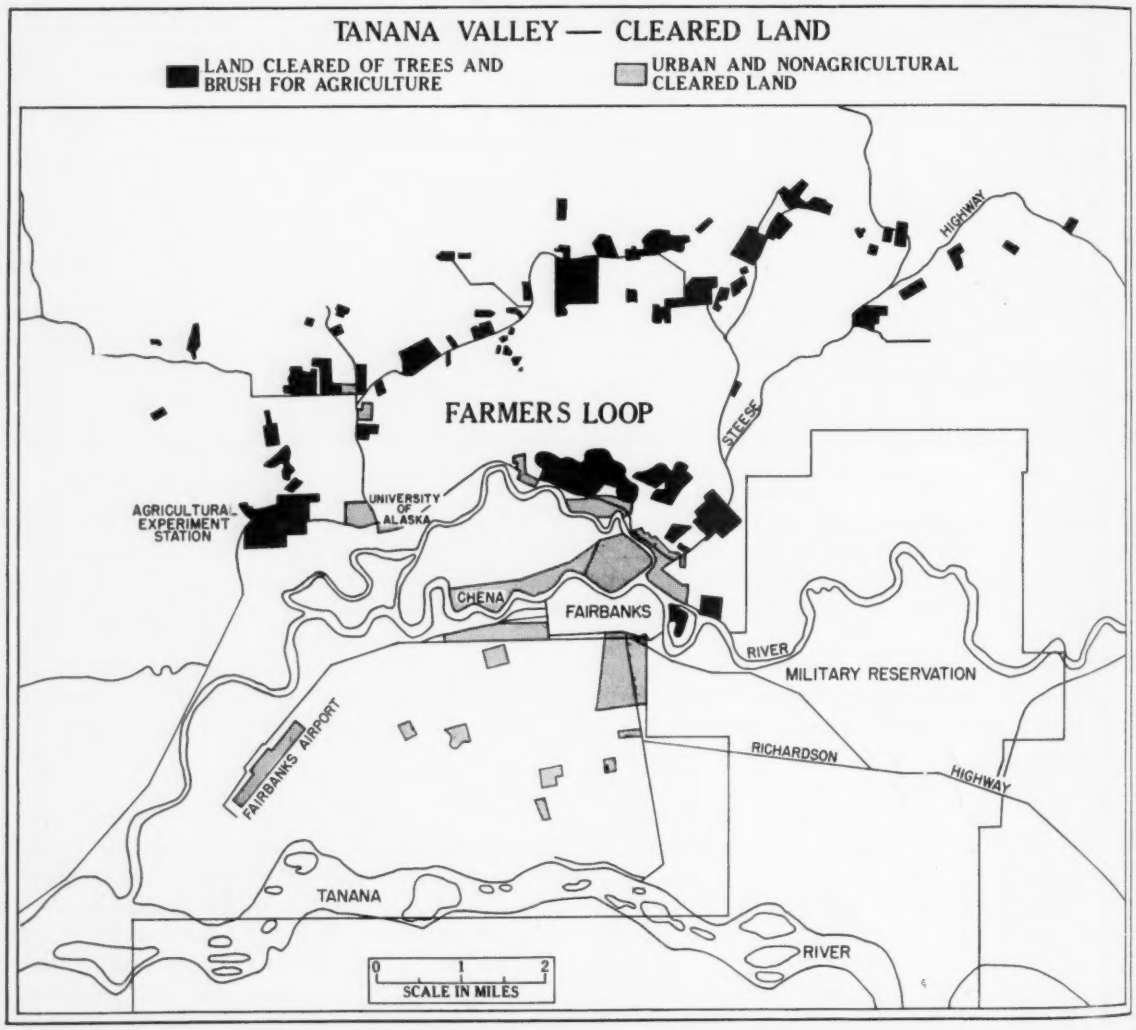


Fig. 3. Cleared land in the Fairbanks region.

FIG. 4. Over-all view of a commercial truck farm in the Farmers Loop.

region is well over $1,000,000. An estimate of the amount produced in the farm belt is approximately $150,000. There is, thus, abundant opportunity to extend local production.

The typical commercial truck farm in the Fairbanks area usually has less than ten acres in cultivation (Fig. 4). The homestead is a one-story building, commonly built of logs, with not more than three or four small rooms. Since farming is done entirely by mechanical power, there may be a lean-to or shed to store the tractor, plow, harrow, cultivator, and usually a potato planter and digger. About half of the truck farmers have chickens, with flocks ranging in size from half a dozen to more than 1,000. Because of the limited income from such a farm and the long period of winter idleness, the owner usually seeks work in Fairbanks during the winter months. For the most part, farm production is limited to hardy vegetables. In the Fairbanks district, among other vegetables, approximately 80,000 pounds of cabbage, 65,000 pounds of turnips and rutabagas, 30,000 pounds of greens, 24,000 pounds of radishes, and 15,000 pounds of celery were produced in 1950. Tomatoes and cucumbers usually do not grow successfully unless they are started in a greenhouse.

Of the vegetables, potatoes are most important and have long been the leading cash crop. Through experimentation several varieties have been produced which thrive under Alaskan conditions. The Irish Cobbler, Eureka, American Wonder, White Harvest, Arctic Seedling, Swiss, and White Bliss are commonly grown. Yields vary from 60 to 250 bushels per acre, depending largely on physical conditions. The average truck farm has 8 acres of potatoes, and the potato farm averages 13 acres. The larger growers are well equipped with power tools and implements to plant, cultivate, harvest, and sort their crops. In recent years over 125 acres have been planted in potatoes, and the total yield has been 600–800 tons annually. The present acreage of potatoes is greater than can be consumed by the civilian population, and part of the crop is sold to the military establishments.

Subarctic regions present a number of significant environmental and economic problems in agricultural production. One of the most important is the combination of a short growing season and low soil temperatures. On August 18, 1950, at 2:00 P.M. the temperature at the Fairbanks Agricultural Experiment Station was 82°; at only 6 inches below the surface it was 59°; at 1 foot, 54°; at 2 feet, 53°; and at 3 feet 49°. The soil temperature to depths of 2 feet on cleared land is above 50° for less than two months during the growing season. These low soil temperatures greatly retard plant growth.

Experimentally the surface soil temperature has been raised in a number of ways, the simplest of which is to spread coal dust on the ground. By spreading coal dust over fields about April 1, at the rate of one pound per square yard, the snow covering can be melted in twelve to fourteen days, whereas the depth of snow on an undusted adjacent field will remain at 12–20 inches until the end of the month. In interior Alaska April is the brightest month of the year, and the variation in melting is due largely to the absorption of radiant heat on the surface of the snow.

During the growing season coal dust is also spread between rows of vegetables such as beans and squash, which require relatively high temperatures. The soil temperature in dusted rows is

2–4 degrees higher than in undusted rows. This increase is sufficient to speed the maturity date of the crop as much as ten days.

In 1949 Basil M. Bensin, agronomist at the Alaska Agricultural Experiment Station in Fairbanks, began experiments with special solar radiators and reflectors to create a garden microclimate with higher soil and air temperatures for growing warm-season vegetables such as beans, cucumbers, and tomatoes.[5] The solar radiator consists of a sheet of corrugated roof iron with dull black strips that absorb and radiate heat, and bright aluminum-painted strips that have maximum reflecting power (Fig. 5). These strips face southward, and the vegetables are planted in rows extending east to west within the reflecting angle of the radiator. In August 1950, where radiators had been used, the tomatoes were ripe, and had reached a normal size, but where the radiators and reflectors were not used the tomato plants bore no fruit. Squash plants were nearly 50 per cent larger when grown with the radiators. This method of vegetable production is costly, however, and can be practiced only on a limited basis.

In the Tanana Valley there are periods, especially in the spring, when rainfall is insufficient for the most rapid growth of horticultural plants. Supplying supplementary water by irrigation is an important problem. Normally, vegetable yields with irrigation are three times as high as when rain alone is the source of moisture. Wells cost from $200 to $1,000 to drill, and are not practical in some sections because of permafrost and lack of free water in the subsoil; then the entire water supply must be hauled from streams.

In a pioneer country, where only a small part of the total area is cleared, wildlife does some damage to crops. Rabbits are particularly destructive pests in vegetable gardens, and in the Fairbanks district they were particularly plentiful in 1905, 1913, 1924 and 1925, 1935 and 1936, and were again numerous in 1945. The cyclic appearance of the rabbit is not fully understood but is generally believed to be influenced by the food supply. When abundant, they must eat all types of vegetation, including woody plants, because the quantity of food is limited. On this diet the animals become emaciated and die, and it appears to take them from eight to eleven years to increase to large numbers again.

Agriculture in Alaska is also faced with economic problems. At the present time the Tanana Agricultural Co-operative Association has only 34 members, and large-scale marketing is handicapped as a result of limited production. The association grades and markets the products of about half its members, but some farmers prefer to do their own grading and marketing. The cooperative has one small underground storage cellar, but most farmers do not have adequate storage facilities, and in 1949 about one quarter of the potato crop spoiled because of poor storage facilities. There are no canning facilities in the region. Consequently, most

FIG. 5. B. M. Bensin inspects peas grown with and without benefit of radiator.

vegetables must be sold at the peak of the season in August and September, when the market is glutted and prices are at their lowest. In 1950 one farmer was building a combination abattoir and cold storage plant for local meats, wild game, berries, fruits, and vegetables.

Farmers have no monopoly in supplying vegetables for local consumption even during the summer. Several factors enter into this situation. The unreliability of the amount of production is a serious handicap. There is little planning as to what crops should be produced. As a result, there may be, for example, a surplus of carrots but few beets. Also, a partial crop failure may result from some unforeseen weather condition. Some farmers are well versed in good marketing procedures, but many need specialized guidance. A system of standards composed of uniform grades that are acceptable to the trade should be developed and enforced. The Alaska Commissioner of Agriculture in 1949 prepared a preliminary set of standards, which have not yet been adopted in this area.

Retailers have also found that they must carry imported along with Alaska-grown produce if they are to satisfy some customers. In many cases it is more convenient and just as profitable for retailers to purchase their vegetables in the States. In consequence, many merchants prefer to import all their vegetables. If the Alaskan farmer could guarantee a given quality and quantity at a given time his market would be greatly expanded.

Labor is another problem because of the large number of workers required for planting, weeding, cultivating, and harvesting. There has always been a shortage of labor and as a result costs have been high. In order to secure workers the farmer must compete with the mining industry—and in recent years with the national defense program. Since 1946 a farm laborer in the Fairbanks area has received an average of $1.50 an hour, which is usually more than the truck farmer can afford to pay and at the same time obtain a fair profit on his crop. Although there are many problems associated with vegetable production, more than 90 per cent of the farmers of the area are primarily engaged in this type of farming.

To supply the need for animal feed, grains were early produced in interior Alaska. All the hardy grains have been grown successfully in the region, and production appears to have increased up to about 1920. In 1919, a peak year, 22 farmers in the Tanana Valley reported a production of 1,128 bushels of spring wheat, 2,811 bushels of oats, and 121 bushels of barley.[6] The high price of flour stimulated wheat growing, and the future outlook for grain production appeared so bright that in 1918 a small mill of 25 barrels per day capacity for grinding wheat was installed in Fairbanks. This plant was abandoned in the late 1920s, however.

After 1920 the number of work animals declined rapidly, and in 1923, with the completion of the railroad from Seward to Fairbanks, the importation of grains from the United States was greatly facilitated. With the competition the grain production of the area has gradually declined, and production of wheat and barley, as commercial grains, has virtually ceased.

Oats are the most important grain crop today, occupying possibly as much as 30–40 per cent of the agricultural land. Canadian and Finnish varieties are among the most successful, for they mature in a period of 80–105 days and yield 20–80 bushels per acre. However, more than 95 per cent of the oats are cut when green for use as animal feed in the dairies. In recent years the dairies have been attempting to produce more animal feed locally and thus reduce imports. The production of grass for hay has never been important in the region, largely because August is the wettest month and grass will not dry in the fields. This fact is responsible for increased production of silage crops. A mixture of Siberian peas, barley, and oats has been found to be an excellent animal feed, and yields are about 1¼ tons per acre.

Although production has not been important in recent years, it is significant that the Agricultural Experiment Station (Figs. 6, 7) is now producing varieties of grains that will thrive in subarctic areas.[7] Barley is the safest grain crop, and both hullless and hulled varieties are grown. From a seeding of 80 pounds per acre on the Experiment Station plots, with an application of about 100 pounds of commercial fertilizer, yields of about 22 bushels per acre were obtained in 1949.

Livestock

The livestock industry has always been considered a risk in interior Alaska. Work horses were the first animals in the region. Cows, chickens, and hogs were brought to the area about 1900 to supply demands of the mining camps for meat and fresh milk. At that time milk sold for 50–60 cents a quart, and fresh meat at $1.00 to $1.25 per pound. It was only after great hardships that the animals arrived in the Fairbanks area. Most of them were brought down the Yukon River by barge from the Klondike of Canada to Circle City, and then 160 miles over the Steese Trail to Fairbanks. A little later an alternate route was utilized from Valdez via the Richardson Trail 370 miles north to Fair-

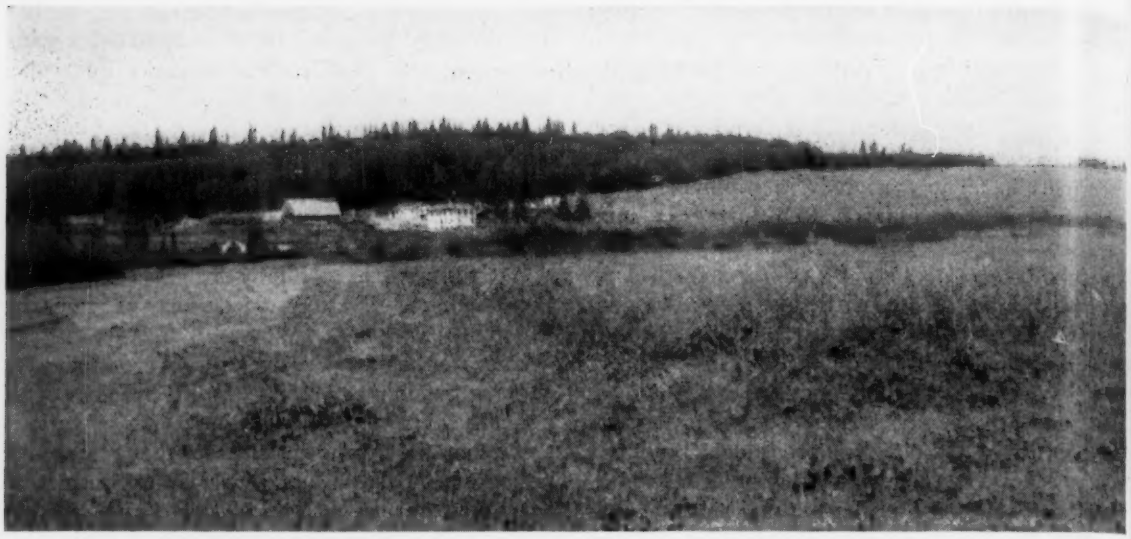


FIG. 6. U. S. Agricultural Experiment Station at College, near Fairbanks. Siberian peas and oats in foreground.

banks. Since hay cost $90.00–$120.00 per ton to import from the United States, emphasis was soon placed on its production. As mining activities decreased, however, and most farmers found it unprofitable to raise stock of any kind, the importation of significant numbers of animals ceased about 1915. At this time, besides work horses, there were only two small dairy herds and a few hogs in the district.

Because of the early difficulties in the animal industry, it was thought that a special breed of cattle should be developed which could thrive under Alaskan conditions. Efforts were made to interbreed the Galloway cattle, which had been thriving on Kodiak Island, with the yak, which was imported from Siberia, and between 1924 and 1930 a number of Galloway-yak hybrids were raised. These animals, kept under conditions that tested their ability to forage for themselves and to withstand the long cold winters, did exceptionally well. During the summer they grazed on native redtop grass, and in winter they were kept in a wooded pasture, with only an open shed for shelter. The meat was reported to resemble beef closely

FIG. 7. Spring wheat plots at the U. S. Agricultural Experiment Station at College.

FIG. 8. Guernsey herd on the Tanana bottom lands near Fairbanks.

in appearance and in taste. Unfortunately, in 1930 the experiment was terminated, and the animals were killed, as a result of a retrenchment of the activities of the Experiment Station. This is an example of an important experiment that was abandoned when the results were just becoming evident. The lack of long-range planning has handicapped many agricultural activities in Alaska.

Another attempt to test the grazing facilities of the region was started in 1927, when 23 bison were imported from Montana and turned loose in the Delta River country southeast of Fairbanks. Although the herd has been given no care, its number is now estimated to be about 400.

At the present time there are two commercial dairy herds in the Fairbanks area, and a small herd is maintained at the Experiment Station. The dairy farms are modern in every way and are not by any means like the small vegetable farms of the region. There are about 100 dairy cows on the farms, mostly Holstein-Friesian and Guernsey (Fig. 8). The care given the cows during the winter is similar to that given animals in the north-central states. During the summer mosquitoes are extremely annoying, and a dark shelter is frequently provided to give some relief to the animals. In recent years the large dairies have increased the growing of silage crops to provide feed, but they still import concentrate feeds and alfalfa hay from the States. The dairies are producing about 1,000,000 pounds of milk in the Fairbanks region annually but still do not supply the entire demand. There appears little likelihood that the herds will be expanded, however, because of the high cost of maintaining

FIG. 9. General view of the largest dairy in the Fairbanks region.

them during the long winter period of indoor feeding and the need for substantial shelters. The estimated cost in 1950 of establishing a modern 12-cow dairy in the Fairbanks district was between $45,000 and $50,000 (Fig. 9).

Hog-raising has increased in recent years, especially on farms with an excess of potatoes and root crops. The largest hog farm has about 300 pigs, which are fed in part on garbage from Fairbanks. Reports from the Experiment Farm indicate that the raising of hogs is still definitely a risk. There is, however, a satisfactory market for locally produced pork, and approximately 350 tons are imported each year for the civilian population of Fairbanks.

Future Prospects

The farm belt of Fairbanks is an established agricultural region. Its area and production will, however, remain small, for the market is limited by interior Alaska's civilian population of about 10,000. To date no agricultural products have been shipped out of the district, nor is it likely that these products will be able to compete in the foreseeable future with those produced in southern Alaska or on the west coast.

This section will probably remain one of the pioneer agricultural outposts of the far north. As a result of experimentation at the U. S. Experiment Station and by individual farmers during the past fifty years, a variety of crops is being developed which are adapted to subarctic conditions. Progress is slow, but the basic work is under way for an expanded agricultural region as the population of interior Alaska increases.

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SCIENCE IN ALASKA

ONE of the significant by-products of the Alaskan Science Conference, held in Washington, D. C., in November 1950, under the auspices of the National Research Council, was a determination on the part of scientists in the Territory to organize into a coherent and effective group. The possibility of using the AAAS as a means of organizing was successfully explored, and in May the AAAS Council authorized the establishment of an Alaska Division of the Association, with two branches—the Cook Inlet Branch, centered at Anchorage, and the Arctic Branch, centered at Fairbanks. Organization of these two branches was completed shortly thereafter. In the Cook Inlet Branch, Don L. Irwin was elected president; Charles S. Wilson, vice president; Mrs. Robert P. Simmet, secretary-treasurer. The Arctic Branch named Andres S. Karstens president; David Stowell, vice president; and John L. Buckley, secretary-treasurer. In June a Southwestern Branch was formed, with Juneau as its focal point. William S. Twenhofel was elected president; W. A. Elkins, vice president; Ralph Brown, secretary-treasurer.

The parts, or branches, did not formally constitute a comprehensive whole until September 4, 1951, when 210 scientists gathered at the Second Alaskan Science Conference in Mount McKinley National Park. Governor Ernest Gruening, chairman of the conference, presided, and Kirtley F. Mather, president of the AAAS, officially installed the new division. The three days that followed were devoted to general and technical sessions and field trips, arranged by a Steering Committee headed by Laurence Irving. On September 8 the new division was organized at a business session, at which Laurence Irving was made president.

The Second Alaskan Science Conference represents the first attempt of the scientists in our northern territory to assemble as scientists to consider problems common to all of them. Although the meeting was supported by the officers of the AAAS, with the cooperation of the National Research Council and the Arctic Institute of North America, its success was assured by the energy of the scientific workers and institutions within the territory. The conference was cosponsored by the University of Alaska, and it benefited in many ways from Governor Gruening's advice in the activities of the Steering Committee and his personal participation in the meetings.

Isolation need no longer be a major handicap in scientific work in the Territory. On a national scale, the Alaska Division joins the Pacific and Southwestern divisions as an integral part of the AAAS. Of greater significance, Alaskan scientists have discovered within themselves sources of information and elements of intellectual and technical strength through intercommunication that will accelerate the tempo of research, and give it the three-dimensional scope it has been so difficult to achieve until now.

SCIENCE ON THE MARCH

A MODERN STATE ACADEMY OF SCIENCE*

A MODERN academy of science has roots that go deep into our cultural and scientific past. The genesis of each academy of science, whether city, state, regional, or national, has been more or less intimately related to progress during the past century and a half in both science and society in the United States. The academy movement has been a direct response to the growth of science and certain social attitudes.

As a prelude to the presentation of reflections on the attributes of a modern state academy of science, it seems desirable to review concisely (1) the cultural and scientific background of academies of science, (2) the origin and growth of the academy movement, and (3) the general growth and existing status of state academies of science in the United States. Then a few academy hazards will be mentioned, and, finally, a brief discussion of some of the present and potential opportunities and responsibilities of a viable state academy of science.

Two general points should be mentioned: (1) Much of this material was presented under the title "Growth of Academies of Science" to the annual Academy Conference held in December 1950 with the American Association for the Advancement of Science at Cleveland; and (2) these are personal points of view, subject to all the vicissitudes of emendation that might ensue from spirited group discussion of this timely subject.

Cultural and Scientific Background

It was inevitable in the evolution of the human mind that science should be conceived, for an inquiring mind linked to perceptive observation had long ago become a dominant characteristic of intelligent, exploring men. In the long, though historically not very remote, pre-science era of his mental evolution, an impelling curiosity about the causes of common natural phenomena led man to many fanciful, childish suppositions. It was also inevitable, however, that with the growth of intellectual discernment, traditional superstitions and fantasies should be swept aside by natural demonstrations and convincing logic. Thenceforth, vigorous mental probing, united to precise observation and blessed by virile intellectual freedom, created a natural scholarly environment in which embryonic science could take root and be nurtured.

The necessary intellectual atmosphere for the gradual development of true science was provided by the fruitful Greek culture of the several centuries before the birth of Christ. The Egyptians earlier had blazed some of the trails. Greek philosophers and logicians thereafter created a milieu in which men dared to make new and refreshing interpretations of nature. This scholarly fearlessness, combined with an instinctive passion for truth, prepared the way for the discovery of the rudimentary verities of physical science. The long-accepted dictum of the universal capriciousness of nature was gradually superseded by the concept that nature's orderly and natural phenomena are the expression of immutable laws.

Upon the decline of Greek culture and the ensuing intellectual stagnation of the Middle Ages, science became dormant. But the innate character of the minds and spirits of sapient men decreed that the eclipse of scientific observation and inquiry should end. The forward march of science was aided in the fifteenth century by the invention of printing type. Numerous orderly and inquiring minds, such as those of Francis Bacon and Descartes, provided new stimuli to natural science and mathematics as a part of the intellectual reawakening of the Renaissance. An environment that had long been virtually barren in respect to the nurture and growth of science now became potentially fecund.

This revival of learning engendered profound stirrings in the imaginations of original thinkers. The solution of numerous critical problems in astronomy, mathematics, and physics had become urgent to philosophic minds as well as to practical explorers. Not much permanent progress could be achieved until more accurate observations of natural phenomena were made and mathematically analyzed in order to formulate and test basic physical laws. Fundamental contributions were made during a relatively brief period by several scientists, from Copernicus to Newton. Within a few centuries, chiefly the sixteenth, seventeenth, and eighteenth, there developed, according to But-

* Based on an address presented before the Illinois State Academy of Science, Bloomington meeting, May 4, 1951.

terfield,[1] "lines of strategic change" in the evolution of scientific thought in which "intellectual knots" were untied. Such a rearrangement of ideas was essential to real progress in science. As pointed out recently by Newman,[2] "this was the transposition of mind required—the new look at nature in order to see what, in fact, there was to be seen rather than what some classical writer had said ought to be seen."

It is unnecessary to recount here the achievements of science during the seventeenth century or to review the amazing progress in the eighteenth and nineteenth. Many minds with unusual capacities for inquiry and scholarship were in ferment. Fortunately for the onrush of science, the mores were becoming in some areas increasingly favorable for unrestricted and unhindered scientific investigation. Inquiries could be made and logical interpretations offered about natural phenomena, including the origin and evolution of the earth, of the universe, and even of man. It was likewise inevitable that reactionary points of view should prevail in some seats of high authority and offer formidable obstacles to straightforward progress in science. Even in these enlightened times scientists sometimes face similar discouragements and baffflements. We hope that an antiscience view is not apt to become virulent under today's conditions of misunderstanding, suspicion, and instability.

Two other features of the evolution of science during the post-Renaissance period should be noted: (1) Scientific disiciplines were becoming progressively established on broad and realistic bases, in numerous respects taking on a modern character; and (2) science is still, in terms of years, very youthful. Physics, for example, dates back mainly to Newton (1687); chemistry to Lavoisier (1790); and geology to Hutton (1800). The youthful virility, aggressiveness, and enthusiasm of true scientists in all fields augur an illimitable future, provided science remains steadfastly anchored in the current mores. We should not forget that sapient man is at least 100,000 years old, that real science is less than 300 years old.

The Academy Movement

With the development of the arts and sciences, circumstances became increasingly favorable to the founding of learned academies. Philosophers, research scientists, and men of letters realized the need of scholarly forums in which the events and currents of the times could be discussed, evaluated, and integrated, both for intellectual satisfaction and for coordination of attacks upon the storehouses of nature's secrets.

The initial precursor of learned academies was Plato's academy, from which the term comes. It was founded about 387 B. C. "for the systematic pursuit of philosophy and scientific research." Aristotle's lyceum, founded in 355 B. C., was another forerunner of modern academies. Models of the original academies throve for about nine centuries, until abolished by Justinian. The first academy that seems to have been devoted extensively to science was founded in the fifteenth century by the versatile Leonardo da Vinci.

The Renaissance provided fertile conditions for the birth and growth of academies. The Accademia Secretorum Naturae, founded in 1560 at Naples, had as a membership requirement some discovery in natural science. It appears to have been the first academy devoted chiefly to science.

Seven academies and learned societies were organized between 1606 and 1666. They included the Royal Society of London (1662) and the French Academy (1666). At least five more were formed during the eighteenth century. Among them were the American Philosophical Society held at Philadelphia for Promoting Useful Knowledge (1743) and the American Academy of Arts and Sciences (1780). The latter proposed "to cultivate every art and science which may tend to advance the interest, honor, dignity, and happiness of a free, independent, and virtuous people."

There are at least fourteen city academies of science. The oldest is the Academy of Natural Sciences of Philadelphia, founded in 1812; the youngest is the Washington (D. C.) Academy of Sciences, organized in 1898. It will be evident later that the academy movement in cities was strong earlier but that it has not kept pace with the founding of state academies. The fourteen city academies have more than 10,000 members, probably about half the total number of members in all the state academies.

There are only six regional academies of science in the United States. One of the most active is the Northwest Scientific Association, in which the normal state academy activities of some of the states in the Pacific Northwest are centered.

There are thirty-eight individual state academies of science. In addition, Colorado and Wyoming have a joint academy of science, and Idaho and Washington participate in the Northwest Scientific Association. States without state-wide academies of science include Arizona, Delaware, Maine, Massachusetts, New Jersey, New York, Rhode Island, and Vermont. Some of these areas have active somewhat localized academies, such as the New York Academy of Sciences, which meets at the

American Museum of Natural History in New York City.

Two of the state academies were founded near the end of the eighteenth century, Maryland in 1797 and Connecticut in 1799. No state academies were formed during the first half of the nineteenth century. Nine were organized in the 45 years from 1850 to 1894, inclusive; nine more between 1902 and 1919. Ten were established during the period from 1921 to 1928, inclusive. During the 1930s, four academies were formed, and four more during the 1940s. The total number at last report is thirty-nine.

Purposes stated by the various academies, so far as published, include eighteen different objectives, which may be grouped into ten principal categories, as follows: Stimulation of research in science (15); promotion of scientific interchange and acquaintance among scientists (10); diffusion of scientific knowledge (10); unification of scientific interests in the state (8); stimulation of interest in science (5); encouragement of publication (5); interpretation of science to the public (2); promotion of formal education in science (1); cooperation of science and industry (1); and assistance to state government (1). The names of the sections of some of the academies indicate that the above list is not comprehensive.

Published data on state academies of science[3] show that twenty-two academies list thirty-seven differently named sections, as follows: Agriculture, anthropology, archaeology, astronomy, bacteriology, biology, biologic sciences, biologic sciences applied, botany, chemistry, conservation, earth sciences, economics,† education,† engineering, entomology, forestry, geography, geology, history,† history of science, industry and economics, mathematics, medicine, medical sciences, mechanical science, mining, natural and physical science, philosophy,† physics, physical sciences, political science,† psychology, science education, social sciences,† sociology,† statistics, wildlife, and zoology. Some overlaps are obvious. Some academies combine two or more of the named sections into single sections, e.g., astronomy and mathematics, geology and geography. Among the 22 state academies of science, the fields of most interest as expressed by the number of section listings are: chemistry (21), physics (19), zoology (16), geology (15), mathematics (14), botany (12), and psychology (11). One section in each of the following fields is listed among the twenty-two academies: Applied biological sciences, archaeology, earth sciences, entomology, forestry, history, industry and economics, mechanical science, medicine, mining, natural and physical science, political science, statistics, and wildlife. Activities of some of the state academies apparently correspond rather closely to the trends of science teaching and the economic applications of science in particular states.

The number of sections in individual academies ranges up to a maximum of fourteen. Two academies have sections on the history of science. Three have sections on science teaching, science teachers, or science education. Similar sections are desirable in each state academy of science to provide strong links with the teachers of science in our secondary schools. Another long step forward could be made by a modern state academy of science. Provision should be made for forums of scientists who have broad, related interests in borderline areas involving problems at the state level. Some state academies solve this problem in part and meet the opportunity by forming a few sections that comprise closely related disciplines. Any modern state academy of science would better meet its opportunities and obligations if a section, or session, could be provided for alert nonprofessionals.

The Illinois Academy of Science now has about 900 members. It was exceeded in 1950 by the Virginia Academy with 1,087 members, Ohio Academy with 1,193 members, Indiana Academy with 1,241 members, and the Michigan Academy of Arts, Sciences and Letters (which is not wholly comparable) with 1,900 members. The California and Texas academies in 1948 had more than 1,000 members each. The total membership of the state academies in the nation is 17,000–18,000. It is of interest to note that although membership in most state academies of science is unrestricted one academy requires at least five years' work in science, or five years on a faculty, or some noteworthy contribution to science. It is also interesting that the total membership of the state academies is about 10 per cent of the professional scientists of the United States. Not all academy members are, nor should they be, persons who have science as a vocation. But many more active scientists of the nation should be members of state academies of science.

The common type of academy publication is an annual volume. A few academies publish a journal which is issued monthly, bimonthly, quarterly, or irregularly. Three academies publish news letters. Most academies are handicapped in the publication of papers of worth to the several sciences, the authors, and the state by the inadequacy of publication funds. Fortunately, in Illinois,

† Exclusive of sections in some state academies of arts, sciences, and letters.

as in some other states, this problem has been solved by the appropriation of state funds for publication. One state legislature recently made available $10,000 for the publication of a monograph prepared by the state academy of science, with proceeds from copies sold to go to the academy treasury.

Academy Hazards and Opportunities

Some academy members and officers may think than an academy of science in this age of science faces few hazards. The obvious handicaps are not too serious, for, recognized, they can be methodically overcome. Much more dangerous to the vitality of an academy and its effective service to science and society are those insidious weaknesses that have arisen from changing circumstances in science, society, and the philosophies of politics. Worthy of mention are inadequate attention to potential research scientists and gifted teachers of science among high-school students; lack of inspired interest in effective teaching of the history, principles, and methods of science; and too scant or too dilatory participation in the solution of the mutual, pressing problems of science and society. Many vexing problems require the best thought of scientists, such as those gathered into a modern academy of science, rather than the ineffective attention of politicians. Long-continued complacence on the part of a majority of academy members may lead to atrophy. Academies should have long-range programs adapted to modern realities, especially to the changing patterns in the public and governmental aspects of science.

The numerous state, city, and regional academies of science have well served certain ends during the past century and a half. Yet many opportunities for more effective service to science, to academy members, and to their communities await full realization. These need rather critical analysis and long-range consideration. Only suggestions can be given here.

Membership opportunities. The state academies of science can meet their peculiar responsibilities and opportunities only through their participating members. An ideal state academy should have several categories of membership:

1) Professional members, so to speak, would be those scientists who are occupied with science as a vocation, whether in teaching, industry, technical bureaus, research organizations, or governmental agencies. They would be chiefly responsible for the conventional program of the traditional academy meeting and be mentors for some other classes of membership.

2) Teachers of real science and of general science in high schools should comprise a much larger percentage of academy members than at present. In fact, the progra of a modern state academy of science should be so in ing that high-school teachers would seek academy me bership. This group is the real key that will unlock doors of science—often appearing mysterious, someti forbidding, to high-school students and some of th elders—to many of the shapers of the future fortune America. About 80 per cent of high-school students have few educative contacts with the principles and me ods of true science after they graduate. The second school teachers and leaders, knit closely together in z ous academy groups, could bring many parents and co munity citizens to a fuller and more stimulating und standing and appreciation of the role of science in mod society. This group of members would probably acco plish more by organizing as a distinct section of the ac emy, in collaboration with their educational associatio The point is illustrated by the New Mexico Academy Sciences, which is affiliated with the state educational sociation and holds annual meetings with it.

3) Graduate students in colleges and universities shou be brought into academy activities and associations means of a separate section and program. The advanta of annual intermingling and of papers and discussions the graduate level are obvious.

4) Undergraduate students in colleges and universiti who have had at least some work in science, should for a collegiate section of an academy, as is done under ab leadership in the Illinois Academy of Science. This grou should not be limited to majors in science, for it is high desirable that students who will eventually follow othe vocations maintain an active interest in science, either an avocation or in some form of community activity.

5) High-school students who have a lively interest science, especially those who are motivated by the spir of exploration and discovery in experimental science or field observations and study, should be brought within th sphere of activities of a modern state academy of scienc This can probably best be done by means of junior aca emies, or junior sections, as in the Illinois academy. Suc groups need, of course, a teacher-sponsor and an academ leader, both of whom should be keenly aware of their o portunities to aid in the molding of many future citizen They should have their own special program at the annu meetings of an academy. A part of it should consist scientific exhibits, perhaps competitively chosen throug community and regional exhibits and "science fairs." A important feature from the standpoint of sustained inte est by both students and their adult friends is substanti public recognition at a general session of the academy the winners of honors in the state science talent search The next point is considered equally important: Th high-school teacher-sponsors should likewise be given ap propriate public recognition at the annual meeting of th academy. Widespread lay interest has been created b some academies through such activities.

6) The amateurs who have an interest in science— often a very extensive one—should become more closel related to a state academy of science, to their mutual ad vantage. This class of members would be composed mainl of collector and nature study groups, with some independent individuals who have distinctive scientific avocations.

7) Laymen who wish to keep informed about the ac tivities and progress of science in general, or in particular fields of individual interest, or as a factor in community programs, should be sought as academy members. Most o them could not participate in, or even follow, the conven

al science programs of academy sections. The case was ently stated by Dr. Edmund W. Sinnott[4] in his 1949 sidential address to the American Association for Advancement of Science: "If science is to develop orously and serve the world as it ought to, it should be wrapped in mystery but must be understood, at st as to its spirit and methods, by those ordinary citi- s upon whom it has to depend for support. The best sible means for bringing this about is a widespread ticipation of laymen in scientific work." The writer uld place the emphasis upon advantages to the partici- ing laymen rather than upon the possible economic nefits to the scientists with whom they might associate.

Science teaching does not always and every- ere inculcate in high-school and college students important principle—the scientific method of ving problems—an invaluable asset in their ntal equipment as they later try to deal with e complexities of modern society. Too much ucation today does not teach students how to ink, or how to do things. As mentioned before, bout 80 per cent of our high-school graduates go t into the world ill-equipped to understand ience as a factor in their own daily lives and in e broad problems of government and the evolving cial order. As Millikan[5] stated recently: "The y to the future of America clearly lies in the condary school because it is the only American stitution that now reaches practically the whole ncoming generation." Here is a challenging pportunity for a modern state academy of science.

A modern state academy of science could aid otably in the search for and recruitment of alented teachers of science—a need more critical han that of gifted high-school students to pursue ience as a vocation. Considerably more progress ould be made if those teachers could receive etter public recognition of their services to the ocal communities and to the state. The state academy of science should use every opportunity to ring this opportunity to realization. As a sug- estion—why not select each year an outstanding eacher of high-school science in the state and confer appropriate recognition at the annual academy meeting?

That "the science club offers a master key to science endeavor among high-school students" is not fully comprehended by some academy members and some teachers. Several million students are available for science club opportunities. We realize that not all of them are innately gifted for such an activity, and none should be forced into it. Two requisites for better realization of the promising possibilities are teachers with the personalities to guide the local club, and appropriate provision for the science club activities to be integrated into the curricula. More recognition of the value of the work, and direct aid by academy members in their communities, in addition to the recognition given through the junior academy at the annual academy meeting, would be beneficial. It is of interest to note that about a third of a million boys and girls from the ages of ten to twenty are members of the science clubs now affiliated with the Science Clubs of America under the active sponsorship of Science Service.

"Can you recognize a young scientist when you see one?" The obvious answer points to the need of the science talent search. This fine steppingstone to advancement should be available to all high-school seniors, and perhaps juniors, in every state. Even though the search is nationally sponsored, the state academy should be more than a mere participating member. Here is a ready-made opportunity for the academy to do some of its best work in advancing both science and public education in science in all parts of the state. An unremitting search should be made for talented students in the smaller high schools, particularly in rural areas. A valuable human resource is all too apt to be wasted in some communities.

Another phase of the science talent search is a search for students and teachers who combine an understanding of science with a gift for its literary interpretation to the lay public. This is a paramount need of the day.

"Now that the United States has assumed the major responsibility for leadership in international affairs," states *Antioch Notes* in a recent issue, "the need for an informed public is greater than ever. . . . The public is nowhere adequately informed. . . . It takes skill, intelligence, and background for [the reader] to keep effectively informed." This means in part that the jargon of the sciences must be translated simply, accurately, and interestingly so that educated people can pick up the trails of science from recognizable starting points and be guided in their intellectual travels by clear signposts. The president[6] of the Ohio Academy of Science in his 1949 presidential address called for a "million interpreters" of science to produce the "ten million scientists" demanded by Dr. Sinnott in his presidential address.[4]

The really critical factor in these times is the inability of the public to weigh the elements involved in all grave public problems at all levels, from the local community to the nation. This is understandable when we recall that about 98 per cent of the adults in the United States have little or no personal participation in the activities of science, and most of them have scant knowledge of its *modus operandi*. What an enormous group of

intelligent citizens awaits comprehensible interpreters! What an opportunity for a modern state academy of science!

An entire discourse could be devoted to the problem of state conservation. Two points must suffice here: (1) We have willy-nilly a pressing need of retreats from the clang and clatter of our modern mechanistic methods of attempting to live lives that are rewarding to us personally and to society. It takes only a little thought to realize that sanctuaries are as much a need for men and women—and children—as they are for wildlife. (2) No group is better qualified than an alert state academy of science to survey objectively and thoroughly the major problems of conservation and to offer solutions in the general public interests.

Many opportunities for effective service through science beckon to a modern state academy of science fully aware and jealous of its role in the activities of the state. Some goals that academies have long had need to be restated, and procedures revitalized. Action to result in worth-while accomplishment is entrusted to those academy members who will pool some of their energies to do the indispensable hard work. Not otherwise can any academy keep in the van of the steady forward march of science and society.

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NEW TORTILLAS FOR OLD MEXICO

The present-day tortilla has come down through the rise and fall of several civilizations with very little modification. In fact, in many remote parts of Mexico, it is still prepared as it was in the days of Cuauhtemoc and Cortes. The origin of the tortilla is lost in the mists of antiquity, but it seems certain that tribes of migrating Indians brought with them the art of torilla-making and established the food in their part of the New World. The tortilla was to the early Indians what bread was to our Pilgrims, and today it is a staple food for millions of people.

To understand what a tortilla is, one must know how it is made. It is assumed that the Indians prepared tortillas by steeping dried whole-kernel corn overnight in heated limewater, the lime being obtained by heating limestone. The treated kernels were separated from the water and ground in a stone mortar (*metate*) to the consistency of dough, or *masa.* The *masa* was kneaded, with the addition of water if necessary, to yield a dough of workable consistency, and a chunk about the size of a golf ball was patted between the hands to make a thin cake. This operation is an art, for it is easy to tear or break the thin tortilla. The tortilla patty was then placed on a fairly hot grill, or *comal,* where it was baked for a few minutes.

The tortilla was eaten hot or warm or used as a wrapper to carry other foods, such as in *tacos* or *enchiladas.* When eaten as it was cooked, it was rolled into a tube, with or without a little meat, chile, and salt, or broken into smaller sections and used as a food-pusher or as an edible spoon.

Today, as in past centuries, the tortilla is prepared by overnight steeping of the dried whole kernel in heated limewater, after which the swollen kernels are drained and ground in a small mill, or *molino,* of two vertically placed buhrstones, one fixed, the other rotated by motor. Dough of the proper consistency is obtained by the addition of small amounts of water during milling.

As a result of today's centralization and specialization *masa* is now often prepared in a small shop, or *molino,* which supplies the surrounding neighborhood with tortilla dough. When the *masa* is ready, it is sold in bulk to the housewives, who take it home in a dishpan or other container (or an apron will do) and pat out their own tortillas. Or, as is the practice in some large towns or cities, women are employed to pat out the tortillas and cook them in the shop, so that they are ready for immediate consumption or may be reheated at home for a later meal. Shops where cooked tortillas are sold are known as *tortillerías.*

The making of tortillas may sound like a small business, but that it is a large-scale business becomes evident when it is realized that in Mexico approximately 96 per cent of the annual production of over 3,000,000 tons of corn is used for food, mostly in the form of tortillas. In years of low production,

Mexico has had to import corn. It is estimated that in Mexico City alone the daily consumption of corn is 1,000 tons. But, since the tortilla-making process has survived unchanged for more than 400 years, the question may well be asked, "Why change?" There are several reasons, such as the desire for a cleaner product and the need for a stabilized product that would withstand the requirements of modern distribution systems. Most important of all is the need of a food product whose nutritional value can be improved.

Officials of the Banco de México were among the first to recognize the shortcomings of the old-time process and, always alert to cooperate in improvement of the nation's health and economy, asked Armour Research Foundation of Illinois Institute of Technology to develop a research program that would determine the possibility of preparing a stable flour for the manufacture of tortillas. The tortilla prepared from such a flour, when ready for consumption, had to be identical in all its characteristics, especially taste, with the standard domestic product.

A stable flour for the manufacture of tortillas would overcome the short keeping period of the *masa* as sold in the market. It would also overcome another decided disadvantage, since the corn dough, as prepared by present methods, offers an excellent medium for the growth of many microorganisms. In low countries where both temperatures and humidity are high, *masa* cannot be expected to keep for more than four hours; in higher altitudes it can be kept for perhaps six hours under very special conditions. In any event, to prevent spoilage, extreme care in handling the dough is required. The Mexican people, realizing that *masa* is not a stable product, bake the tortillas as soon as possible after the dough is prepared; whatever is not consumed immediately may be reheated as needed. Cooked tortillas keep somewhat longer than *masa,* but the reheated product has much lower workability, cannot be rolled, and has lost much of its original flavor. Consequently, most people do not prepare any more tortillas than they can consume at one time.

Banco de México officials recognized the possibility of manufacturing a stable flour that would have a long shelf life and that would not require elaborate equipment to prepare the tortillas required for each meal. The first step was to study existing methods of making tortillas, all of which used the same basic process of preparing the *masa* —steeping in limewater and grinding. Modern installations employed small power-driven buhrstone mills, but the making of tortillas from the *masa* has always been a hand operation. Although many attempts have been made to do the job mechanically, only a few have been successful, and perhaps the hand operation will never be replaced entirely.

The next step was to determine the most suitable manner in which to market the final product. Possibilities included canning, freezing, and dehydrating. Canning was ruled out because of the difficulties of sterilizing the pack without over-gelatinizing the *masa,* and because the costs of operation and containers would not allow the product to be sold in competition with tortillas on the open market. The idea of a frozen *masa* was eliminated because the cost would be too high to compete with regular tortillas. Lack of sufficient refrigerated warehouses and trucks, and of refrigeration, not only in the local markets, but also in the homes was also a factor. Home refrigeration is common among the middle and higher classes, but it is a rarity in the lower income groups, where tortilla consumption is high. Dehydration, then, appeared to be the most promising approach to the problem.

The early stages of the research program were devoted to learning whether the *masa* produced by regular steeping and grinding operations could be satisfactorily dried. We learned in our experiments that *masa* dried by the usual methods resulted in lumps that had to be broken down in a grinder, and that a change in flavor invariably resulted. It was also realized early in the investigation that the germ oil is an integral part of the final tortilla and that dehydration would have to be done in such a manner as not to alter the oil or allow it to become affected in any way. All these observations, checked by experiment, finally resulted in a specially designed drier capable of completely dehydrating the *masa* with no adverse effect on the flour or on the final tortilla, either as to appearance or as to taste. With this knowledge and with the data obtained in the laboratory, a pilot plant was erected to produce about 500 pounds of dry flour per hour. A preliminary market survey showed acceptance by the public of the newly developed product. Today the Mexican people have received, without any complaints or comments against quality, more than 500 tons of tortilla flour, and it can be said that the research work as such has been successfully completed.

The present pilot plant has been in operation for about a year, during which time changes and additions have been made to provide for smoother operation. Also, using the pilot plant results, specifications were evolved for the purchase of production equipment for the establishment of a large commer-

cial plant, which will serve as a model for national expansion of the industry. This equipment is on order and is expected to arrive by the time the new factory building in Mexico City is ready for occupancy. Although the capacity of the plant is only a small portion of the daily requirements not only of Mexico but of Mexico City itself, sufficient quantities of flour will be produced to introduce it to the existing market and to establish a demand for greater quantities. This demand can be met by installing similar units alongside the production lines now being built, as well as in other areas throughout the country.

It may be difficult to create a demand for the dry flour in remote sections of Mexico, but it is anticipated that the cities and many of the larger towns will provide a market that will warrant building milling and drying centers in local areas.

As is the case with nearly every new product, research toward improving the flour and decreasing production costs will continue. The shelf life of tortilla flour is quite satisfactory in high altitudes and dry areas such as Mexico City, and it is expected that through additional research the shelf life in humid tropical regions can be extended to an equally satisfactory period.

It may be possible, also, to use tortilla flour as a means of fortifying the national diet. Because of the widespread use of the tortilla and the anticipated ultimate adoption of tortilla flour, the diet of the entire nation could be enriched by the addition of minerals, proteins, or vitamins that are lacking in the present flour. The fortification of some few constituents may present a problem, but the over-all prospect of raising the nutritional level of the nation by such means appears feasible.

The fulfillment of the first step has been completed—the production on a pilot plant level of an acceptable dry tortilla flour that can be sold at a price that is competitive with that of the present-day commercial tortilla. The next step is already under way—the commercial production of the dry flour and promotion of large-scale customer acceptance. How long it will be before this goal is reached is difficult to say—one year, possibly two. The third step may be enrichment or it may be something else.

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BETTER GRASSES FOR BETTER TURF

THE development of superior turf grasses for specialized uses presents to plant breeders some of the most fascinating, exciting, and richly rewarding opportunities to be found anywhere today in the field of agriculture. The statement that more taxpayers are directly interested in better turf than they are in any other single phase of agriculture has not been contested. There are 25 million or more homeowners who are striving desperately for good lawns against terrible odds. There are millions of golfers who quite naturally *expect* good turf because of the activities of the United States Golf Association Green Section during the past thirty years. Then there are the thousands of colleges and schools whose students have a right to expect good athletic field and playground turf but, sadly, seldom have it. If we had the space to enumerate the many other turf uses, such as for cemeteries, parks, highway slopes and shoulders, airfields, cantonments and drill grounds, tennis, lawn bowling, and others, there would be little doubt left that the development of specialized turf is big business. The growing and selling of seeds of turf grasses are on a major scale, as are the production, distribution, and servicing of turf maintenance machinery. Many thousands of people are employed in various phases of business relating to turf and its uses.

In our attempt to produce good turf for many uses, we find that the weakest part of the system lies in the quality of the grasses available to us. Crab grass, for example, is rated as America's No. 1 turf pest. "Crab grass" is a term that brings dismay every summer to many homeowners. The logical control of crab grass is through the use of desirable adapted perennial turf grasses that are able to replace crab grass. Most of the turf grasses sold in seed mixtures are not capable of producing a turf strong enough to fight crab grass on its own terms. True, the homeowners oft-misguided practices actually may encourage crab grass, but the lawn grass of the future must be able to thrive in spite of these things.

The plant breeder who develops a superior turf grass must first discover how to eliminate disease susceptibility. It is the first law of turf. More than 20 million pounds of common bluegrass seed are sold each year, most of which fails to produce satisfactory turf because it is so susceptible to *Helminthosporium* leaf spot disease. This disease weak-

ns and sometimes destroys common bluegrass during the cool, wet spells that frequently occur in arly spring, leaving the turf thin and weak and asy prey to crab grass and other weeds. The gical answer is not to fight the crab grass with emicals (because it will return) but to replace it ith a better turf grass. Chemicals will be useful as ols in establishing the improved grasses.

The first truly superior leafspot-resistant bluerass ever to be placed on the market was a product f nature's own laboratory. It was found on the eventeenth tee of Merion Golf Club, Ardmore, ennsylvania, and was developed by the USGA reen Section and cooperating agencies primarily r golf course use, where the emphasis is on natral weed control, close mowing, rapid healing of juries, and on perfection in every detail. The performance of Merion (B-27) bluegrass is such that is in heavy demand by all turf interests, to the xtent that growers will not be able to supply the emand for many years to come. The advent f Merion bluegrass is an epic of turf management istory.

Merion bluegrass is not a perfect grass, nor is it "miracle grass," as some ill-advised promoters f sales would indicate in their advertising. It is a rass that should be a challenge to plant breeders. Merion could well be one parent in a breeding proram that ultimately would develop an even better luegrass. A bluegrass like Merion, which is disase-resistant and which thrives under close mowng (or grazing), could be the basis of a pasture ixture, because leafspot and close grazing can in pastures as well as lawns. No plant breeder ver need apologize for considering turf needs on a ar with pasture and forage needs. They are loser than we think.

Another bright spot in turf history has been corded at Tifton, Georgia, where G. W. Burton, eneticist and plant breeder, in a single breeding rogram has developed a superior hay and pasre Bermuda grass and a superior turf type of ermuda grass. The primary objective was forage -the by-product was turf. Many farmers in the outh are enjoying new prosperity because of oastal Bermuda, the improved forage type. Its elds of hay and its rich pasturage have challenged her workers. The interesting by-product of the evelopment of Coastal Bermuda grass has been ifton 57 Bermuda, a disease-resistant turf-type hat is being used on many golf courses and other rf areas throughout the South. It provides users ith better Bermuda turf and causes fewer of the eadaches that are prevalent where the common otton-patch" Bermuda is used. One of the outtanding characteristics of Tifton 57 is its exceptional resistance to several diseases common to Bermuda grass.

Another Bermuda grass selection is the U-3 Bermuda, which has received a great deal of attention and is being used well north of the limit where Bermuda was once thought to flourish. It, too, may be a parent and probably has been used by this time for the development of a new superior Bermuda grass. The U-3 Bermuda does not have all the qualities that we would like to see in a Bermuda grass; eventually, therefore, it must give way to a superior type when it is produced by the plant breeder. Until then U-3 Bermuda will continue to enjoy wide popularity as a fine-bladed, winter-hardy turf Bermuda.

Early in the history of the United States Golf Association Green Section, the primary objective was the development of better grasses for putting greens. The member clubs of the United States Golf Association, with their dues, represented the sole support of the Green Section. Therefore, since the member clubs demanded information on better putting greens more often than anything else, quite naturally the attention of the Green Section was devoted largely to the development of superior types of bent grasses. No bent-grass breeding programs had been developed in the early twenties. Greenkeepers used what they could get. By and by, on some of the older golf courses of the country, notably some of those around Washington, D. C., different types of bents began to evolve in greens that originally had been seeded to South German mixed bent. Upon taking cores or plugs of sod out of some of these patches of bent and planting them in a clean seed bed, it was observed that the selections began to spread. The grasses were types of creeping bents. By this method of selection, which is still being used, a large number of creeping bent types have been selected, tested, and discarded. Only a few types have survived the test of time and use. Two of the most popular strains for putting greens today are Arlington (C-1), and Congressional (C-19), both highly disease-resistant. Other selected strains in use include Cohansey (C-7), Toronto (C-15), Collins (C-27), and Old Orchard (C-52). Metropolitan creeping bent, long a favorite, suddenly disappeared in a span of two years from an unprecedented attack of disease to which this strain of bent was susceptible. Washington bent, another selection, has survived better than Metropolitan, but it is very susceptible to dollar spot and it loses its color rapidly in the fall, when cool weather comes. It is being replaced by better types of creeping bents.

A new development in the breeding of better bents for putting greens is the polycross nursery.

Several desirable types of creeping bents that are the product of rigorous selection are planted side by side in cultivated rows and are allowed to produce seed. The results of this open pollination, termed "polycross seed," promise a very bright future. Naturally, many, many different types of bents will be evolved in this open-pollinated polycross mixture, and this is exactly what most golf course superintendents want. It will tend to develop the best-adapted type of turf regardless of conditions under which the seed is sown.

For more than fifty years we have been seeing occasional plantings of zoysia, but until 1945 no breeding work had been done on this important turf grass. Considerable selection work had been accomplished, but the selections had not been evaluated under actual use. Today at the Plant Industry Station, in Beltsville, Maryland, the U. S. Department of Agriculture and the USGA Green Section are working diligently on the breeding and testing of zoysia grasses, alone and in combination with superior cool-season grasses. The future for lovers of turf is bright indeed. The story of zoysia is fascinating and someday soon it can be told. Of extreme importance is the fact that it produces seed of excellent quality, and already we know many facts about how to use the seed to advantage for establishing turf. Other advantages of zoysia include its ability to thrive on subsoil with little or no organic matter and to produce good turf with very limited amounts of fertilizer. It can go for long periods between irrigations. It is highly resistant to insects and disease and it can fight crab grass to a standstill under its own terms. Zoysia is at its best in hot weather when bluegrass and fescue are weakest, thus providing an excellent "partnership" that will result in high-quality turf throughout the year. Apparently the zoysia family knows few climatic limitations. Zoysia needs less mowing than most other grasses to maintain acceptable turf. This in itself is a great advntage to the homeowner.

During the past twenty years another chapter in turf-breeding history has been developed at the Pennsylvania State College, where H. B. Musser has been working with bluegrasses and with red fescues for at least that long. With assistance and encouragement from the USGA Green Section and from Oregon seed growers, the fescue-breeding program has assumed new and important proportions. In the testing plots at Penn State and at Beltsville several of the new types of creeping red fescue, the result of the Musser breeding program, have outstripped all others in the field of performance. They have been able to succeed even though planted in the spring in our Washington climate. They have been able to survive repeat attacks of crab grass and have emerged the winn They are disease-resistant and they tole ate clo mowing. Steps are now being taken to produ commercial supplies of seed of these superior fe cues. Testing is going on to determine wheth they will combine with Merion bluegrass. This is question to which everyone immediately wants know the answer, because the seedsmen have bee selling fescue-bluegrass mixtures for many year All too frequently, however, they have not pr duced a satisfactory lawn because the old mixture have contained only disease-susceptible grasses.

What will these new improved grasses mean the discouraged homeowner? We know that the will be better home lawns with less effort and wi fewer disappointments. People will begin to enj their lawns and to look upon them with prid Weed problems will be minimized, and few periods of irrigation or sprinkling will be require Attention will have to be given to insect control, always, but the effort will be more enjoyable an worth while because the results will be so muc more gratifying. As these better grasses becom available to the homeowner there will be less ne for quick-growing temporary or special-purpo grasses such as rye grass, redtop, and timothy. Th improved strains will do better without the comp tition of these "pretenders."

Another extremely important feature of the im proved turf grasses that are being developed pr marily by and for golf interests is that they ca be mowed closely without injury. This is demande in good golf turf and is preferred by most hom owners. Until now we have had to tell the hom owner to mow turf high, in order to give the law a fighting chance against disease and weeds. No he can mow his lawn as he likes it. Most law books and bulletins will shortly have to be revise because high mowing of the improved turf grass actually can be detrimental. This situation w exist so long as the grasses developed for golf tu are used on the home lawn. For example, near every disappointment that has been record against Merion bluegrass to date has occurre where the owner was mowing high (1½–2 inches as he has had to do to keep common bluegras High mowing (1½ inches) of Bermuda grass or of zoysia tends to be detrimental to good lawn tu and, of course, cannot be tolerated for golf tur This news will make many homeowners happy.

We have often heard the homeowner's plaintiv request for "a lawn grass that will grow two inch high and stop so we won't have to mow it." Amon golf course superintendents it is well known th frequency of mowing is a large factor in producin

a firm, dense, well-knit turf. In general a turf deteriorates in direct proportion to the span of time between mowings and thus to the amount of grass removed at each mowing. Infrequent, high mowing produces stringy, "leggy" turf that has little resistance to wear. Close, frequent mowing tends to create dense firm turf that is far more wear-resistant. This fact is neglected most often (of all places) on athletic fields. The mortality of the turf during game time on a wet field is all too well known to require comment here.

The day of better turf with better grasses is here not only for golf but for (at long last) the homeowner and all others who want and appreciate the best in turf. It should be recorded that the tax-paying public is indebted in a large measure to golf for the improved turf grasses that are being grown today for all turf uses. The steady insistence of greenkeepers and golf course superintendents to the United States Golf Association Green Section and the U. S. Department of Agriculture for assistance with their turf management problems has been almost wholly responsible for the steady progress and growth of knowledge of better turf. The assistance of cooperating state experiment stations has been an inevitable development, with a few pioneers leading the rest. As a result of the development of the coordinated national turf program we find that there is as great a need for extension teaching as there is for practical research. This service, a function of state extension services, is being requested in several states at the present time.

Thus we see that, within the past few years, turf management has begun to assume its rightful place in agriculture on a par with other specialized sciences. The fact that virtually every living person is affected by and is deeply appreciative of good turf lends popular support. The need for good turf of many kinds by the armed services and by highway commissions lends dignity and necessity to this new agricultural science, which heretofore has had to struggle along with insufficient funds. Popular demand on the homeowner front alone should bring about a growing recognition of the need for better grasses for better turf.

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FIFTH ANNUAL INTERNATIONAL PHOTOGRAPHY-IN-SCIENCE SALON

Entries in the Fifth International Photography-in-Science Salon, sponsored annually by THE SCIENTIFIC MONTHLY and the Smithsonian Institution, should be sent (prepaid) to the Editor, *The Scientific Monthly,* 1515 Massachusetts Ave., N.W., Washington 5, D. C., Nov. 1–Nov. 27. All accepted photographs will be shown at the AAAS meeting in Philadelphia Dec. 26–31, and later throughout the United States. For entry blanks and full information write to *The Scientific Monthly,* 1515 Massachusetts Ave., N.W., Washington 5, D. C.

BOOK REVIEWS

THE LIFE OF SCIENCE

The Heavens Above. J. B. Sidgwick. xv + 333 pp. Illus. $4.00. Oxford University Press, New York. 1951.

Johannes Kepler: Life and Letters. Carola Baumgardt. 209 pp. $3.75. Philosophical Library, New York. 1951.

IN PART, at least, *The Heavens Above* seems to be an outgrowth of World War II. With the blackout in England, and the duties of airplane watchers and others who had to give their attention to the sky at night as well as by day, the stars were brought strongly into the consciousness of many Britons who had previously ignored them. For the benefit of such enforced star-gazers, Mr. Sidgwick, who was a British naval officer, wrote his *Astronomy for Night Watchers,* which was published in the United States as *Introductory Astronomy.*

Later, in 1948, *The Heavens Above* was published in England, and it so appealed to Warren K. Green, who is professor of astronomy at Amherst, that he arranged to revise it for a U. S. edition, which is the volume before us. The exact nature of these revisions is not indicated, but apparently they were largely to remove references that would have been familiar only to a British reader. In any event, Green has admirably succeeded in his aim, in doing the rewriting, to reproduce Sidgwick's pleasing style. It would be difficult indeed to distinguish between the work of the two authors.

Starting with such familiar matters as the observed motions of the heavenly bodies, including, for example, the fact that Mars sometimes seems to reverse its movement for a time, the first chapter states the problem. The second chapter—The Problem Solved—deals with the real motions that produce these effects, telling how the ancients attempted to explain them, in the Ptolemaic theory, and how they are explained today.

From consideration of distances, and how they are measured, the authors work outward through a discussion of the distribution of the stars to the form of the galaxy, and the presence of other galaxies, thus ending the first half of the book, which is devoted to Quantity —A Geometric Picture.

The second half is on Quality—The Nature of Things, and it starts off with a description of the spectroscope, by which so much of this knowledge has been secured. Having got the matter of movement out of the way, the work proceeds unhindered with descriptions of what the sun, moon, planets, stars nebulae, and galaxies really are, as far as we can tell. An appendix gives a brief introduction to the problems of spherical astronomy, such as the coordinates used by astronomers, and the determination of time.

Though such an arrangement differs considerably from that of the conventional text on astronomy, it seems to be a very logical one, which would adapt it to the needs of the teacher of an introductory course, as well as to the individual reader who wishes to increase and organize his knowledge of the heavens above.

Mrs. Baumgardt's little biography of one of the great figures in the history of astronomy, who played a major part in bringing it to the state described by Sidgwick, is apparently the first to make use of the great two-volume collection of Kepler's letters to the leading scholars and other important figures of his time, which was published in Germany in 1930.

By a judicious selection of extracts from these letters she has given us what is largely an autobiographical account of Kepler's career. In his communications to his friend and equally great contemporary, Galileo, we see how Kepler's ideas were developing. And we also can appreciate his many woes: the death of his wife and of one of his sons, accusations of witchcraft leveled against his mother, the failure of the Emperor Rudolph to pay him the "rather honorable allowance" that had been promised. Despite all these troubles, Kepler preferred to remain in German surroundings and turned down attractive offers from the University of Bologna and later from England.

Though it necessarily lacks the completeness of a larger work, this book does make available in English much information about Kepler that previously was lacking, and as such it is a useful addition to Kepleriana.

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HOW WE SEE THINGS

Individual Differences in Colour Vision. R. W. Pickford. xvii + 386 pp. Illus. 30*s.* Routledge and Kegan Paul. London. 1951.

R. W. PICKFORD, senior lecturer in psychology at Glasgow University, presents in this book a report of researches in color vision which he has carried out over the past eight years. Eleven hundred normal and 178 color-deficient individuals were tested in a variety of experiments. The results of the tests had not been previously published, and the data are valuable for the understanding of variability among individuals with normal color vision and for the measurements of color deficiency.

Dr. Pickford has approached the problem from the side of direct color experience, and his thinking is probably different from that of those students whose approach is from the structural or physiological end of the chain of events. But, whatever the approach, this work has implications for our thinking on the basic mediation of color perception.

When one considers the manifold problems of color

vision, it seems the best part of valor to accept expert opinion. Yet expert opinion is rarely unanimous. The effort by Dr. Pickford is related in part to a most fundamental problem in color vision—namely, the nature and number of the color receptors. This problem is one that has stimulated a good deal of argument and research in the past, and it is by no means settled. It is fair to say, however, that most of our experts hold to a trichromatic theory. It was the work of the late Selig Hecht that provided for a generalized acceptance of the Young-Helmholtz theory of three types of receptors. Most certainly Hecht believed, as do many of our significant workers in color vision, such as Wald and Judd among others, that the whole color domain may be described adequately in terms of three variables. The problem of polychromatic as opposed to trichromatic theories is not a new one. The basic difficulty seems to be that the evidence presented against a trichromatic theory is not quite overwhelming enough to destroy such a formulation completely and to insist, as in the present book, that a four-color theory derived from Hering be adopted.

Pickford feels that the results he presents, mainly from a psychological—or, better said, psychophysical—attack on the problem of color matching by a wide variety of individuals, are convincing evidence of the need for at least a four-component theory. He ties up his findings with the newer work of Hartridge on microstimulation of the retina and of Granit on electroretinography. Pickford advocates a form of the four-receptor theory with a separate response system for brightness as the more adequate representation of the situation.

Several major experiments are described with full details, including an array of well-described individual cases of interest. The first and last chapters deal with general problems of color vision and are excellently done for the general reader. The other eight chapters present the results of various techniques and situations of testing with normal and deficient subjects. Statistical treatment and presentation of the results are well done. Many topics are treated, including heredity, age, sex, race personality, training, and occupation.

Pickford indicates that the type of investigation described in this report is only a start. He hopes to organize a survey of at least 10,000 individuals in the British Isles in such a manner that comparisons of such factors as age, sex, occupation, geographical region, intelligence, color training, interests, and personality may be studied. This is a large program and would be worth the effort.

Pickford writes exceedingly well about these most complicated matters, and he is to be congratulated on the publication in book form of his extensive series of studies. Whether his ideas will be adopted is not of great import to this reviewer. He has taken some good psychophysics and applied it with good statistical knowledge to the measurement of a complex kind of judgment. At times he has demonstrated a high level of clinical insight into the subject's behavior and has been able to avoid some of the pitfalls of the measurement of such judgments.

The findings are not final, nor will they be treated as conclusive, I venture to add, by many workers in this field. But possibly the impact of this major work will be a reconsideration of some notions we have accepted. At least there is much to be gained by a recognition of the wide nature of individual differences in color vision and of the great difficulty in measuring the differences. As a contribution to methodology, if nothing more, a step ahead has been made here. The work of Pickford should provoke discussion in technical circles. The general reader should be interested in it also, since it can be understood without great technical background. As a lesson in the history of scientific development, it is worth looking at seriously.

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MOUNTAINS FOR SPORT

Climbs in the Canadian Rockies. Frank S. Smythe. 260 pp. Illus. $4.50. Norton, New York. 1951.

THIS is a book of happy adventure in remote and ever-beautiful places, among mountains that casual visitors to the more accessible travel spots in Canada's West can only appreciate from a distance. The beauty and majesty of unfamiliar spires in the Canadian Rockies as captured by the author's camera and as painstakingly reproduced by the publisher are in perfect harmony with the descriptive skill Frank Smythe uses in painting his word portraits. His deep love for new vistas, untrod peaks, endemic flora, and little-known dwellers of field and stream stands out like the colors of a knight in gleaming armor.

This is the perfect answer to those who ask, "Why bother with such impossible climbs?" or "What do you get for all the discomfort of sleeping in the open, eating meager rations, risking your life many times for every hour aloft?" To which the author replies:

> I well remember running down the screes [piles of talus or rock waste at the base of a cliff] which had been so unpleasant to climb, in a matter of minutes, and of taking great leaps and driving my heels into their yielding surface with the same delight as our hairy ancestors experienced when they danced on the slain bodies of their enemies. [Or, in a less aboriginal vein, perhaps]: It was a queer reflection to know that in all those hundreds, perhaps thousands of mountains which vanished over the horizon's brim, not one had been climbed. We stood in the midst of a virgin land. In the prosaic century in which we lived, where politicians are seeking to reduce life to a formula, it was still possible to escape to a land unmeasured and unexplored. No doubt it will all be mapped in the future, probably from the air, but for many years its peaks and lakes and valleys will be safe from the clutch of civilization.
>
> Beneath us stretched the glowing expanse of the ice field, laid like some spotless linen cloth between the mountain tops. It was a discovery, and happily, one that had no commercial value. It was something that no man had trodden, or wanted to tread, except for one man. . . . We spent some time on the summit in the sun, noting as far as possible, details in the panorama.

Here is a book for all lovers of the great outdoors, for the amateur as well as the experienced climber. Elementary details are included in the text in such a way they do not intrude upon the story the veteran climber wants.

Some of the peaks described offer no difficulty at all to the physically able. Ascents along strata that are gently inclined give the beginners satisfying thrills and a deep feeling of adventure in exchange for little effort. But where the strata are steeply tilted, greater experience is needed; and when peaks are vertical the chimmeys and cracks that produce jagged pipe organ effects offer even greater challenges. In Part I of this book the author deals solely with the Canadian Rockies between Whitehorn Mountain, on the north, and Victoria Peak, close to the United States border on the south. This is the area most popular with those contemplating mountain holidays in Canada.

Part II takes in the ranges of British Columbia, the Selkirks and the Coast Range, where granite peaks are as steep and difficult as the aiguilles of Chamonix on Mont Blanc. Here climbing is every bit as good as in the mountains of Switzerland.

The idea for this book was born when the author, a distinguished British mountaineer, accompanied a military mission to the United States and Canada. The mission had as its principal objectives the ordering of American mountain and skiing equipment, and the selection of a training area for the Lovat Scouts. a British regiment which had been detailed to receive instruction in high-mountain warfare of an Alpine nature.

Certainly there can be no doubt in any reader's mind about the ruggedness of the areas selected, after reading Smythe's latest great adventure. Mountaineering in that part of Canada does not consist of walking up a well-graded path to a hut, or ascending by funicular to a comfortable hotel, and spending the next day climbing a mountain along a route scratched and grooved by the feet of many predecessors—a compact and beautifully bound guidebook in one pocket and a detailed, large-scale topographic map in another.

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VOYAGE TO THE MOON

Rockets, Missiles, and Space Travel. Willy Ley. xii + 436 pp. Illus. $5.95. Viking, New York. 1951.

THE appearance of a new book by Willy Ley is a treat for both the literary and the scientific reader. *Rockets, Missiles, and Space Travel* is a rewritten version of *Rockets and Space Travel,* but it contains so much additional material that it may be considered as practically a new book.

Rocketry, until the development of the V-2, was considered by most people to be either fictional in its concepts or a quirk of fanatics. Such an amazing attitude of mind was found in 1940 even among the technically trained. But this is not in keeping with the ancient history of the use of rockets as weapons of warfare. The concept of space travel dates back at least as far as the Greeks, and at one time it was a race between rockets and conventional artillery as to which would dominate in warfare. Fiction has had an important role in indoctrinating mankind into the concept of space travel—far more so than research until the past few years. Rocketry may therefore be considered as a clear-cut case in which fiction prepared the minds of many people for the ultimate utilization long before engineers and scientists dared hint at such an achievement. To engineers rockets meant war rockets and probably still do to some with limited imaginations.

The work of Goddard in America and Oberth in Germany heralded the beginning of the successful engineering of liquid-fuel rockets. Solid-fuel rockets are definitely limited to warfare, or as boosters for liquid-fuel rockets. In order to get the type of power plant required for space travel, liquid-fuel rockets are essential. The greatest advance in rocketry prior to 1945 probably took place at Peenemünde, Germany, and culminated in the V-2, the liquid-fueled rocket used to bombard England during World War II. An important aspect of the V-2 is that there is no known defense against such a missile at the present time.

Parallel research in America resulted in the development of the rocket plane, X-1, and the high-altitude rocket, the WAC-Corporal. After 1945 German rocket science was grafted onto the American. The Viking, which is designed to reach ultimately about 350 miles, may be considered the first result of the marriage of German and American rocket science. It is highly probable that even more important developments, such as high-altitude interceptors, have reached a practical stage. For obvious reasons achievements would not be publicized.

The actual penetration of free space by the WAC Corporal, which was fired in a two-step rocket using a V-2 as the lower stage, was accomplished on February 24, 1951. This feat removed space travel from the field of fiction into an engineering probability. Ley also discusses the space terminal, which has been considered in its elementary form as a rocket satellite by the United States. However, the true terminal in space would be of much greater importance than a rocket satellite, owing to its practical value as a fueling station for flights to the moon and the planets.

Ley limits his discussion of fuel problems primarily to chemical fuels, because whatever work has been accomplished in the application of atomic energy to rockets has not been made public. His discussion of gravity in Chapter 10, The Rocket into Cosmic Space, emphasizes our present lack of knowledge of gravitational fields. He points out the logical weaknesses of the hypothesis of a gravity screen, a device that has often been used by writers of science fiction as a means of conquering free space.

Appendix I, Rocket Airplanes and Rocket-assisted Take-off, is practically a chapter in an engineering text. Appendix II contains 28 tables, and sections on the engineering characteristics of rocketry, with some of the historical aspects of particular interest to the specialist

A complete and erudite chart of high-altitude meteorological conditions and observations is pasted in the back of the book. This is a comprehensive and reliable summary of known knowledge in this field.

Ley's new book upholds his reputation of being an interesting as well as informative writer, and anyone interested in rocketry and the next frontier of engineering achievement, space travel, will find his book both useful and enjoyable.

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SCIENCE AND PHILOSOPHY

The Impact of Science on Society. Bertrand Russell. vii + 64 pp. $2.00. Columbia University Press, New York. 1951.

THE writings of philosophers are not in general easy reading for physical scientists, and (I suppose) vice versa; but the present reviewer unexpectedly found this book to be rather easy reading. It may therefore be recommended to other scientists and to lay readers. It contains three lectures delivered by Lord Russell at Columbia University on the subjects "Science and Tradition," "Effects of Scientific Technique," and "Science and Values."

In the first lecture the author recounts the effect of science on unfounded traditional beliefs. One of these was the regarding of comets as portents of revolutions, war, and pestilence. With the progress of astronomy and the establishment of Newton's law of gravitation, comets were found to be no more supernatural than planets, the only difference being in the degree of eccentricity of their orbits. Still the victory of science in this case is not yet complete. Today's many devotees of astrology regard the planets as possessing the power of governing the future of individuals born under their influence.

In the second lecture the author points out that in the late Middle Ages two scientific discoveries were made that have had a profound influence on later civilizations—gunpowder and the mariner's compass. Nothing of equal importance occurred in later economic history until the age of steam and the industrial revolution at the beginning of the nineteenth century. The next important effect of scientific technique was in electricity—the telegraph and the telephone. These instruments increased the power of central governments and diminished the initiative of distant subordinates. This made possible organizations covering large areas. At the present time a new technique—the utilization of atomic energy—is still in its early infancy; it will doubtless have a greater effect on civilization than anything that has preceded it.

In the third lecture the author speaks of the kind of philosophy that seems to be suggested by science in modern times, and of what hopes for mankind science has rendered possible. The philosophy that has seemed appropriate to science has varied greatly from time to time. In Newton's day in England, in spite of Copernicus, man was still the *moral* center of the universe and the principal concern of God's purposes. This philosophy suffered various changes; and now modern astronomy, picturing to us the immensity of the universe with its multitude of stars like our sun, probably also with planetary families and possibly with living creatures here and there, rather reduces our human race to an insignificant episode in the universe. Science used to be valued as a means of getting to know the world; now, owing to the triumphs of technique, it is conceived as showing how to change the little world on which we live. This raises the question of what hopes for the world are legitimate and rational in the existing situation.

Science can abolish excessive hours of labor. The invention of the cotton gin and of other types of agricultural machinery illustrates this. The growth of the science of medicine has conferred an immense boon on mankind. In the eighteenth century people expected most of their children to die before they were grown up. The situation began to improve in the nineteenth century, chiefly owing to vaccination. The sum of human suffering has also been much diminished by the discovery of anesthetics. Moreover, there has been an increase of opportunity. It is much easier than it used to be for a young man without inherited wealth to rise to a position where he can make the best use of his talents. The waste of talent in former times makes the author say: "I shudder to think how many 'mute inglorious Miltons' there must have been."

Finally, the author says: "There is more diffused happiness than ever before, and if the fear of war were removed this improvement would be very much greater than it is. . . . The near future must be either much better or much worse than the past; which it is to be I do not know, but those of you who are still young will know before very long."

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UNDERSTANDING SCIENCE

The Early Development of the Concepts of Temperature and Heat. Duane Roller. iv + 106 pp. $1.25. Harvard University Press, Cambridge. 1950.

THIS is No. 3 of a series of "Case Histories in Experimental Science." Numbers 1 and 2 were first released in Conant's Terry lectures delivered at Yale in 1946 and later in 1947, published as a part of the book *On Understanding Science—An Historical Approach.* The editor of the case histories, Dr. Conant, considers

> the purpose . . . [is] to assist the student in recapturing the experience of those who once participated in exciting events in scientific history. . . . The [essential intent is], . . . by the intensive study of the actual work of some of the past . . . the methods they employed [may] stand out clearly. . . . With [such] an introduction . . . the inquiring citizen ought to be in a position to continue his scientific education throughout his life.

The booklet under review presents a brief account of the caloric theory, traces the evolution of the thermometer, and spotlights the investigations of Joseph Black, from which the concepts of specific heat and latent heat emerge; describes Count Rumford's experiments, which contributed to the decline of the caloric theory and the growing acceptance of "heat as a form of motion" for explaining thermal phenomena; and discusses Humphrey Davy's experiments as contributors of evidence leading to the modern theory of heat.

The author documents his presentation with generous offerings of quotations lifted from the actual written reports of the three investigators mentioned. He does an excellent job of integrating the excerpts by his interpretative interpolations.

The booklet has, as a sort of appendix, ten pages of questions, presumably for classroom use. There are three pages of bibliography listing 56 references. Booklets such as this should greatly facilitate a "closer integration of sciences with the humanities . . . and . . . contribute to the participation of science in the program of a general education."

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HISTORY OF AN IDEA

Evolutionary Thought in America. Stow Persons, Ed. x + 462 pp. $5.00. Yale University Press, New Haven, Conn. 1950.

THIS volume, prepared for the special program on American Civilization at Princeton University, consists of three essays on the theory of evolution, and eight on various aspects of its impact and influence on evolutionary thought in America. All are authoritative, although they vary widely in style and scope.

The three introductory essays are on "The Rise and Impact of Evolutionary Ideas" (Robert Scoon); "Evolution in its Relation to the Philosophy of Nature and the Philosophy of Culture" (F. S. C. Northrop); and "The Genetic Nature of Differences among Men" (Th. Dobzhansky). The first of these is a broad survey of the history of the idea of organic evolution, comprehensive but rather too sweeping to be accurate in all details and points of view. The contribution by Northrop is characteristic of this author. Most of the ideas will be familiar to those who have read *The Meeting of East and West* or *The Logic of the Sciences and the Humanities.* The treatment of Aristotle's place in the conception of evolution appears to confound Aristotle's ideas about the development ("evolution") of the individual and the great scale of being with a genuine conception of organic evolution in the modern sense. At least Northrop's views are quite at variance with those of such a modern scholar of Aristotle as Edelstein. Turning to Dobzhansky's contribution, we find a clear and comprehensive discussion of the genetic principles that underlie human variation and are consequently basic to a sound application of evolutionary thinking to other fields.

The fields of American thought influenced by evolution and discussed here are as follows: sociology (Robt. E. L. Faris); political and constitutional theory (Edward S. Corwin); economics (Joseph J. Spengler); psychology (Edwin G. Boring); literature (Malcolm Cowley); architecture (Donald Drew Egbert); moral theory (Wm. F. Quillian, Jr.); and theology (Stow Persons). The panorama is interesting indeed, although limitations of space prevent more than a few comments. Social Darwinism, through such protagonists as William Graham Sumner, Lester Ward, and John Fiske, plays a prominent part in a number of these essays; but the important influence of evolution on American thought through such founders of pragmatism as Chauncey Wright and Charles S. Peirce, and so brilliantly delineated by Philip Wiener in his recent book, has escaped the attention of the present group of contributors. The same current of evolutionary thought, through Nicholas St. John Green and Oliver Wendell Holmes, Jr., has had an overwhelming influence upon our legal and constitutional traditions—but this has been altogether overlooked by Professor Corwin. On the other hand, the essays on economics, psychology, moral theory, and theology are particularly valuable for their broad scope and their critical, exhaustive treatment of their respective subjects.

It may seem straining a point to have included literature and architecture. This has been done by identifying evolutionary thought in American literature with naturalism, exemplified in the work of Eggleston, Howe, Howells, Norris, Dreiser, and London as pioneers and of numerous later writers; and in architecture with organic expression and functionalism, exemplified in the buildings of Louis Sullivan, Frank Lloyd Wright, and Walter Gropius. The bond is there, if rather tenuous. These two essays remain interesting and valuable in their own right.

One may conclude that although this collection of essays is by no means a definitive work on the subject, nevertheless it fills a real need and will be useful to students and stimulating to general readers. It is surprising that no general assessment of the important influences of evolutionary thought in America had been made previously. Princeton (and Yale) deserve credit for the undertaking.

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CENTRAL FACTS OF BIOLOGY

The Life of Vertebrates. J. Z. Young. xv + 767 pp. Illus. $8.50. Oxford University Press, New York. 1950.

BIOLOGY, as seen through the offerings of American colleges and universities, consists of a rather standardized set of courses. In any particular subject emphasis may vary from institution to institution and from instructor to instructor; the same can be said about texts. Different books in comparative anatomy, for example, have emphasized such aspects as morphology, taxonomy, physiology, embryology, and paleontol-

ogy. In many the subject matter has been largely oriented toward man. Although *The Life of Vertebrates* should probably be classed with textbooks of comparative anatomy, it has overflowed conventional boundaries and covered much that has heretofore been presented only in books dealing with other aspects of biology. In it the author has made "an attempt to define what is meant by life of vertebrates and by the evolution of life." As a consequence one discovers in its chapters not only what one is accustomed to find in comparative anatomy texts, but much more. The emphasis is on the "central fact of biology, that life goes on." Thus one finds material of ecological, physiological, and biochemical nature reinforcing the anatomical and evolutionary. There is a chapter on man's impact on fishes, in which the concept of the biomass is well presented, and another on the behavior of birds. Such topics as the dynamics of flight in birds are given more than passing notice.

There are 32 chapters. The arrangement is systematic, proceeding from the earliest chordates (in spite of the title!) to the mammals. A uniform treatment is given each group, beginning with external features and going on to the skeleton, muscles and locomotion, feeding and digestion, circulation, respiration, excretion, reproduction, the nervous and sensory organs, and behavior. Although some 200 pages are devoted to the ancestry and classification of mammals, their structure, function, development, and evolution within the class have been left for a second volume.

Whether this book will be popular among college students is a question. To many of them comparative anatomy is just a requirement or a recommended course for medical school. These are the premedical students. But there are others, students with a broader appreciation of biology. The former group could profit by using this book; the latter may be more apt to enjoy it. Where comparative anatomy is taught as a one-semester course probably few instructors will attempt to use the book because of its length. In year courses it should fit better.

Despite the breadth of coverage, the book seems to be remarkably free from errors. References arranged by chapters are given at the end, much increasing the value of the book.

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MODERN AGRICULTURE

Crops in Peace and War. The Yearbook of Agriculture, 1950–1951. Alfred Stefferud, Ed. 942 pp. Illus. $2.50. Superintendent of Documents, Washington, D. C. 1951.

AN IRATE poinsettia grower has recently written to one of the trade journals that three different experts at Beltsville have given advice of "no earthly use." He points out that for fifty years he has been a successful poinsettia grower "without photoperiods, inhibitory influences, dissection, primordia, cyathium, meristem, anthesia, etc."—all of which were flung at him by the cloistered scientists of Beltsville. "No, sir, I just used good soil, remembering . . . that there is nothing better to mix with soil than old cow manure, but be sure it is from an old cow!"

There could scarcely be a better peg upon which to hang some notes on this most recent issue of the yearbook of agriculture. For both the poinsettia grower and the Department of Agriculture represent trends that are symptomatic. The grower—or he might just as well be an equally successful farmer—is rightly impatient when the erudite terminology of botany is dished out to him, instead of down-to-earth information. For there are pedants at Beltsville just as in any other seat of learning.

The USDA, on the other hand, as every scientist knows, must rear its research program upon basic science, and the terminology of this, if not always its content, is appalling. Actually, it is fit only for the technical journals and even the abstracting of it has reached astronomic heights.

The sponsors of the present volume seem to have realized some of this in choosing the subjects to include and particularly the men and women to write about them. The result is an amazing amount of information, though much of it is still beyond the ken of the poinsettia grower, and of many others. Hence the editorial wisdom of including a 29-page glossary. There is also a pretty comprehensive index. What one hopes for is that future volumes will always contain such good indices, but be guided by an editorial policy that makes a glossary unnecessary. For the book is not, and should not be, a textbook for experts, but for the average intelligent reader who wants to know what recent developments in agriculture are really significant.

In a brief review it is impossible to note even a fraction of the more than 140 separate articles. They are grouped under headings such as "Food, or Feed or Fabric," "Starch Has Many Uses," "Vegetables and Some Fruits," "Oilseeds, Oils and Fats," "To Keep Us Well," etc. Nearly all the articles deal with the modern utilization of crops, scarcely at all with the growing of them. One of the best is on "Fermented Soy Foods and Sauce," which, although extremely informative, does not drive one inevitably to the glossary.

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GERIATRIC MEDICINE

Disease in Old Age. Robert T. Monroe. xi + 407 pp. $5.00. Harvard University Press, Cambridge, Mass. 1951.

THE relatively new clinical field of geriatric medicine is growing rapidly both in scope and in urgency. As in the development of all new areas of thought, ideas, theories, and generalizations are formulated first; a later step is the careful accumulation of objective information on a scale large enough to be statistically valid. Geriatric medicine cannot come into its

own until a vast body of facts has been accumulated, digested, and absorbed.

Dr. Monroe's monograph—an analysis of the clinical and pathologic records of nearly eight thousand patients aged sixty-one or over admitted to the Peter Bent Brigham Hospital, Boston, in the thirty years from 1913 to 1943—is a major contribution in this direction. The statistical analyses are significant in giving us essential information concerning incidence, complications, progression, and overlapping of disorders, and they clearly demonstrate the interaction of multiple chronic diseases accumulating as age advances. It is not surprising that data re-emphasize the importance of increasing variation with age. The socioeconomic factors in chronic illness are pointed up with convincing statistical evidence.

The style is precisely factual, and tabulations present the material in a concise manner. The typography is excellent. The author is to be congratulated upon a magnificent contribution to the field of geriatric medicine, for he has refined the ore from a rich mine of information. As a reference source the volume will be of great value, not only to clinicians dealing with the elderly, but also to epidemiologists, sociologists, and biologists concerned with the growing and complex problems of gerontology.

EDWARD J. STIEGLITZ

Washington, D. C.

BRIEFLY REVIEWED

Paul Ehrlich. Martha Marquardt. 255 pp. $3.50. H. Schuman, New York. 1951.

IN THE spring of 1876, while Paul Ehrlich was an undergraduate student at Breslau, Robert Koch, an unknown physician, presented to the faculty and student body unequivocal proof of the germ nature of disease. This was one of the great landmarks in the history of medicine. During Koch's stay in Breslau he visited the various research units and was taken to the laboratory desk where Ehrlich was investigating the staining reactions of dyes. There are no records of other than casual remarks passing between the two on this occasion, yet within six years Koch was destined to discover the causative agent of tuberculosis and Ehrlich to collaborate in the development of a special staining reaction that led to the recognition of the germ in infected tissues. This was an achievement of great personal significance, since Ehrlich shortly thereafter developed tuberculosis and went to Egypt for two years to overcome the affliction. On his return to Berlin, Koch provided a position in the Institute for Infectious Diseases, where Ehrlich plunged into his lifework of attempting to unravel the mechanisms by which the body resists infectious agents. As a result of these studies, he shared the Nobel prize in medicine in 1908 with Metchnikoff, of the Pasteur Institute of Paris.

The author of the present biography, Martha Marquardt, served as Ehrlich's personal secretary from 1902 until his death in 1915, an interval that covered the second phase of his scientific career, often designated the Frankfurt era. Here his researches on chemotherapy, particularly the discovery and development of the clinical use of arsenicals in the treatment of syphilis, became world-famous. Miss Marquardt presents an intriguing account of the brilliant mind and kindly nature of this great medical scientist. Those who saw *The Magic Bullet,* the motion picture depicting the life of Ehrlich, will enjoy this book. It should be in the hands of every chemist as well as every individual interested in the health sciences.

Nature's Ways: How Nature Takes Care of its Own. Roy Chapman Andrews. 206 pp. Illus. $3.75. Crown Publishers, New York. 1951.

MANY of the color illustrations that embellish this book should be familiar to those who read advertisements, for they are the highly finished paintings of various animals distinguished for their peculiar camouflage, protective behavior, or other habits that originally were used to demonstrate the virtues of being well insured. To these have been added a large selection of black-and-white illustrations, mostly from photographs, and a simple, descriptive text. "It is a book," in the words of the anonymous author of the dust-jacket "blurb," "for every American home, with great permanent appeal for young and old." It is indeed a fine gift book for an inquiring adolescent, in spite of the mild flavor of Lamarckism that now and then creeps into the commentary.

Annual Review of Physical Chemistry. Vol. 1. G. K. Rollefson and R. E. Powell, Eds. vii + 382 pp. $6.00. Annual Reviews, Inc., Stanford, Calif. 1950.

THE publication of this volume initiates for physical chemists an annual service in their field that has been available to biochemists for the past 19 years. The volume's preface promises that "in general, the topics to be selected will follow those common to textbooks in physical chemistry. Allowance, however, will be made for added topics in order to give adequate coverage for new fields as they appear as well as to allow for variations of activity in the older ones."

Volume 1 lists 18 topics in which the time spread, for the articles inventoried for the individual chapters, varies from one to fourteen years, the median being about four years. The bibliography lists some 2,500 titles. In addition to these references which follow each chapter, an author index of more than 2,400 names and a subject index of 1,500 or more subtopics indicate how useful the work will be to the seeker of reports from others in his field.

Finding such reviewers as Rossini for Thermochemistry, Hildebrand for Solutions, Wheland for Valence, Mann for Spectroscopy, Daniels for Kinetics, Taylor for Catalysis, Noyes for Photochemistry, Mark for Polymers, and Weiser for Colloids instills confidence in the charac-

ter and objectivity of the reviews in this first volume.

This publication, and its successors, should be of especial worth to teachers of physical chemistry as an aid and a stimulus to keeping their course offerings up to date, to graduate students looking for a field of research, and to the industrial specialist directing his attention to broader fields of scientific advance and as an antidote to his impulse to stay too closely within the groove of his narrow field of specialization.

The table of contents of the second volume, which is to be issued this year, is released on page vi of this one. It fulfills the reader's expectation that future issues of this resource publication will be comparable with Volume 1.

Cooperation Among Animals—With Human Implications. W. C. Allee. xiv + 233 pp. Illus. $3.50. Schuman, New York. 1951.

THIS is a revised edition of *The Social Life of Animals,* which appeared in 1938. Professor Allee's researches in animal aggregations are well known to biologists, who are familiar with the older edition of this book, and the new edition should find its audience in a new generation of both biologists and interested laymen.

There are few books in which a scientist has discussed his favorite researches so clearly and concisely as this, and answered the questions as to their meaning and value almost as soon as the reader can ask them. There are morals to be found in these studies of anthills, cockroaches in a maze, flocks of birds, and clusters of sea urchin eggs, and they are presented without emotional prejudice. Still another great war has made the old arguments about the inevitability of war and its utility as a population check less tenable than ever, and we can only hope that the time described in the book's concluding sentence will not be too long delayed: "Unlike ants or chickens or fishes, man is not bound over to form castes or peck orders or schools, or to wait for a reshuffling of hereditary genes before he can discontinue behavior that tends toward the destruction of his species."

A Hundred Years of Physics. William Wilson. 319 pp. $3.50. Macmillan, New York. 1950.

THIS book, the latest of "The Hundred Years Series," may be regarded as an abbreviated treatise on theoretical physics, but in saying "abbreviated" the reviewer does not mean that anything of importance has been left out. The book covers the development of the subject from the beginning of Queen Victoria's reign to the atomic bomb, describing the discovery of the cardinal facts of physics and the growth of its unifying theoretical structure. Being addressed to both students and teachers of physics, the mathematical side of the subject is unavoidable; and, naturally, in compressing this into small volume, the author has encountered difficulties. For instance, the discussion of Einstein's general theory of relativity is limited to eight pages. All that is possible under such circumstances is to state the lines of thought that lead up to the final conclusion, with a skeleton outline of mathematical formulas, and to refer the reader to the original publication for more detailed information. The book contains an abundance of footnotes and a bibliography that will be of value to the student.

The author begins with a prologue giving a general view of the state of physical science at the beginning of the period the book covers and concludes with an epilogue summing up the development of the unifying theoretical framework of the subject. The teacher of physics, with his general knowledge of the facts, will find it to his advantage in reading this book to begin with the prologue and the epilogue, leaving the intermediate chapters for later reading.

The reviewer has noticed only one place in the book where there is a confusing error. On page 68, in discussing the mean free path of gas molecules, the author quotes Clausius as regarding a gas as composed of spherical molecules, all having the same diameter σ. The formulas which immediately follow use σ as the *radius* of the molecule.

In the 21 chapters more than a hundred topics are discussed, and nothing of importance has been left unmentioned. The book is well worth the attention of students and teachers of physics.

James Lind, Founder of Nautical Medicine. Louis H. Roddis. 177 pp. $3.00. Schuman, New York. 1950.

THOSE who had the good fortune to read the booklet entitled *Edward Jenner and the Discovery of Smallpox Vaccination,* published by Dr. Roddis two decades ago, will enjoy the present volume. The story of the Scottish naval surgeon, James Lind, focuses attention on an achievement in preventive medicine: the prevention and cure of scurvy by the administration of orange, lemon, or lime juice, which occurred half a century before the experiments of Jenner. Jenner dealt with an infectious disease, Lind with a food-deficiency disease; both were scourges of mankind and both have become preventable diseases through the efforts of these two physicians.

The reader will promptly discern that the author has enjoyed gathering the material for this book. He has presented his findings as a kindred spirit who has had firsthand contact with nautical medicine. The book can be highly recommended.

LETTERS

THE FOUR IMMORTALS

Lingula, Lingula, little tongue of time,
speaking to us now from Ordovician stone,
standing on your sand tube in bilious tidal slime,
clearly comes your signal on the cosmic dial tone.

Sphenodon, Sphenodon, with greenish catlike eyes,
with spiny intimations of stegosaurian pride,
with double thymus promise of Mesozoic size,
you give a Permian echo: the world and time are wide.

Ostrea, Ostrea, benthonic hatchet-foot,
pellucid luscious morsel, sessile margarite,
you bring Triassic tidings and on our table put
the pure molluscan blessing, the gourmet's dear delight.

Didelphis, Didelphis, with pouch and grasping tail,
and grasping hallux, too (surely, kin of man!),
our dim Cretaceous cousin behind the unrent veil. . . .
How mighty are the modest in the geologic span!

Sapiens, Sapiens, the self-observing beast,
the Pleistocenic mammal with four immortal friends:
perhaps he may continue while sunlight is released—
but none will note his passing when his sojourn ends.

READ BAIN

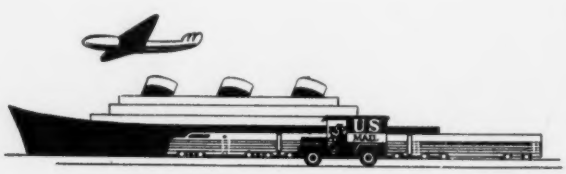
Miami University
Oxford, Ohio

TOO FAR TO THE LEFT?

As you said in the July issue when you headed the letter of a correspondent regarding the education controversy, "Editors are human." So I do not blame you for the, to me, extremely leftist slant of two articles in the same issue, namely, Albrecht-Carrié's "Of Science" and Stewart's "Human Adjustment to Social Law." You had in mind, no doubt, the enlivening of the journal by getting away from strictly scientific papers.

Of course, as usual, the authors disclaim any such tinge. Thus Stewart says (p. 59), "It may be thought that this is advocating 'socialism,' but there is danger in the acceptance of any set formula of this sort." However, throughout the article he constantly apologizes for the Russian and Communist opposition to us as due to our attitude toward them. His attack on the "autism that dominates the press" sounds very much like what the Communists had to say about the American press during the Oatis trial.

Albrecht-Carrié is entirely wrong when he tries to make it appear (as the left-wingers and fellow-travelers do to lull the unwary into complacency with Communism) that Marxism is nothing but an economic theory. He writes, "There was no need of Marx to convince us of the importance of economics, better named political economy; *in a sense we are all Marxists nowadays* (italics mine). . . . What this reflects is the changed nature of the modern world or, as it has been put, *Marxism* (*meaning the economic interpretation of history*) (italics mine) is truer today that it used to be." Marxism means a great deal more than an economic interpretation of history. It means, as is only too evident today, a complete subjugation of the individual to the state. This includes scientists, as witness the genetics debacle in Russia.

P. H. YANCEY

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